Attachment 1

ITT

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Advanced Engineering & Sciences

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Memorandum

1 March 2011

ESES-11002-2246

To:	Ross Sorci, Joint Spectrum Center, Applied Engineering Division (JSC/J8)
From:	Les Polisky, Comsearch Government Solutions, as a subcontractor to ITT Corporation.
Subject:	Task Order T3168, Review Documentation of Tests Performed on the Alfred Mann Foundation Medical Micropower Network
Reference:	Contract No.: HC1047-07-D-0001

1. The Alfred Mann Foundation (AMF) is developing a Medical Micropower Network (MMN) to aid patients recovering from neurological muscular damage due to injury or disease. The MMN consists of microstimulators, referred to as Interacting System Devices (ISD) that are implanted in a human body, and an external control apparatus, referred to as the Master Control Unit (MCU). The MCU will typically operate within several meters of the patient and will communicate with the implanted ISDs using a Radio Frequency (RF) link. AMF designed the MMN to be frequency agile and proposed to operate on one of four, 6 MHz bandwidth, channels in the 413 – 457 MHz frequency range.

2. To support this design, AMF has requested the Federal Communications Commission to consider adding a medical service allocation in the 413 – 457 MHz frequency band. The 410 – 420 MHz frequency band is allocated on a primary basis to the Federal Government for fixed, mobile, and space research services. The 420 – 450 MHz frequency band is allocated on a primary basis to the Federal Government for radiolocation services and to the amateur radio service on a secondary basis. Since the MMN is proposing to operate on a non-interference/non-protected basis with incumbent operations in the 413 – 457 MHz frequency band; AMF designed the MMN with multiple techniques to mitigate interference into and from incumbent services.

3. AMF requested the Joint Spectrum Center (JSC) evaluate the Electromagnetic Compatibility (EMC) of the proposed MMN with incumbent Federal Government Communications-Electronics (C-E) systems operating in the 410 – 450 MHz frequency band. The JSC completed the analysis and documented the results in report number JSC-CR-10-058. The report concluded that the MMN transmitters should be operationally compatible and not cause unacceptable interference into Government

C-E receivers currently authorized to operate in the 410 – 450 MHz band. The required separation distances to preclude potential interference from Government high powered transmitters into the MMN receivers led to a recommendation to test and determine the effectiveness of the MMN interference mitigation techniques to enable the MMN to operate in a high powered Federal Government system environment. In addition, JSC-CR-10-058 included a recommendation to validate the body loss used in the EMC analysis and the Equivalent Isotropic Radiated Power (EIRP) of the ISD when measured just outside the body.

4. In response to these recommendations, AMF provided the JSC supporting documentation, internal test reports, and initiated testing to be performed by the Aerospace Corporation to determine the effectiveness of the MMN interference mitigation techniques. The Aerospace Corporation completed their testing and AMF provided the associated test report entitled, "*AMF MMN Wired Test Report*", along with AMF documents describing technical parameters and operational characteristics of the MMN to the JSC for review.

5. The purpose of this task was to review the technical documents provided by AMF, and to provide comments on the test procedures, results, and conclusions with regard to the recommendations stated in JSC-CR-10-058.

6. To validate the body loss and ISD EIRP of -20 dBm used in the JSC's EMC analysis, AMF performed measurements and the results were documented in an engineering test report entitled "Uplink Path Loss of Four-Wire Antenna Connection in Simulated FEBPM Implant." The report documented a measured body loss of 1.25 dB/cm. This measured body loss coupled with the antenna efficiency and the location of the embedded ISD resulted in signal levels measured outside the body approximately 20 dB below the values predicted for hemispheric radiators using a dual slope path loss model. This report validates the body loss of 20 dB and the ISD EIRP of -20 dBm used in the JSC's EMC analysis.

7. To address the JSC's recommendation to determine the effectiveness of the MMN interference mitigation techniques, the Aerospace report listed four test objectives to evaluate:

   - MCU's ability to spectrally excise in-band narrowband signals
   - MMN's ability to dynamically switch channels without suspending critical functions
   - MMN's ability to gracefully shutdown in a communication line service-loss scenario
   - MCU's ability to sense the signal level of incumbent systems to avoid the MMN system interfering with them by successfully changing channels.

8. To accomplish these evaluation objectives, Aerospace performed a wired test that interfaced the MCU and ISDs with coaxial cable and other components such as attenuators and splitters used for signal level adjustments and monitoring. The other key testing components were two computers and two Automated Wave Generators

(AWG) that supplied the interfering signals to the MMN components. One of the two computers supplied the instructions to the AWG's to create the potential interfering wave forms from incumbent systems. The second computer executed AMF software to monitor the MCU and record the MCU responses to the test conditions as they occurred. The two computers shared data to correlate the interfering wave forms controlled by the first computer to the recorded MCU responses at the second computer.

9. The wired test configuration allowed for the tests to be conducted with very precise interference and desired signal levels into the MCU and ISD's. The test set up is thoroughly illustrated with block diagrams, photos and the measured signal calibration values are listed in Tables 2 – 5 of the wired test report. To simulate the wireless operation of the MMN and the body loss characteristics in this wired test configuration, the parametric characteristics of the ISD's were modified as described in Section 2.4 Link Signal-to-Noise Ratio (SNR) calculations. The report stated that AMF supplied the test board with the ISD's and included matching networks to equalize gain across the channel frequencies. The matching networks degraded the ISD's noise figure from its nominal 8 dB to 14 dB and reduced the nominal transmit power of the ISD's from 0 dBm to -14 dBm. This was necessary to produce valid measurement results but introduced an artificial element to the MMNs normal wireless operating scenario.

10. The method to generate the RF signals of the incumbent systems was well described in the report and the technical parameters seem to represent worst case operational parameters of potential interfering signals from the tested incumbent systems. The incumbent systems included in the test are listed below:

    - Mobile Radio – data traffic (Frequency Shift Keyed Signals)
    - Mobile Radio – voice traffic (Frequency Modulated Signals)
    - Ground Radar
    - Airborne Radar
    - Amateur Television – Analog (generic wideband signal)
    - Enhanced Position Location Reporting System

11. The wired test performed by the Aerospace Corporation, based on the conditions and assumptions described and the MMN responses documented in the report, achieved the four test evaluation objectives. The wired test results confirm that the MMN interference mitigation techniques tested (narrow band signal excision, dynamic channel switching and MMN graceful shutdown) performed as described in JSC-CR-10-058 for the interference waveforms tested.

12. The scope of the wired test as documented in the Aerospace report was discussed during a meeting with AMF and a subsequent telecom with AMF technical staff on 20 January 2011. Following this telecom, AMF provided additional documentation on 28 January and these documents are provided as attached to this memo. The attached documents are listed below:

- *AMF MMN Wired Test Report.* Version 0.61. Aerospace. 3 November 2010.
- *Uplink Path Loss of Four-Wire Antenna Connection in Simulated FEBPM Implant*. ETR-0155 Rev. 01. AMF. 19 October 2009.
- Email from Howard Stover, AMF on 28 January 2011 included the following attachments
    a. Letter from Howard Stover. AMF. 28 January 2011.
    b. *Description of the MMN Graceful Shutdown Process.* AMF. 20 January 2011.
    c. *AMF MMN Wired Test Report*. Version 0.61 Addendum. Aerospace.
    d. *Number of Interferers/Signal to Interference Level vs. Uplink Bit Error Rate.* AMF. 26 January 2011.
    e. *MMN system operation in the presence of multipath fading narrow band incumbents.* AMF. 28 January 2011.

13. The additional documentation included test results examining the effect of dynamic fading of narrow band mobile radio signals on the MMNs ability to excise narrow band signals, dynamically switch channels and to gracefully shut down. The test results indicate that when the MMN is operating at receive signal level of -63 dBm, the interference mitigation techniques of dynamic channel switching and shutdown continue to be effective during dynamic fading conditions.
14. The Aerospace wired test and AMF documents describing additional test results, MMN operational characteristics, and the MMN graceful shutdown process provides additional substantiation of the results reported in JSC-CR-10-058. The interference mitigation features of the MMN and low-power of the MMN components should prevent unacceptable interference into incumbent Government CE systems. When potential interfering signals from incumbent Government C-E systems are detected by the MMN, the interference mitigation techniques should enable the MMN to continue to operate by either excising the narrowband signal or by dynamically switching channels. In the event that incumbent interfering signals are simultaneously present across multiple MMN channels, the MMN will shutdown to prevent unintended stimulations or responses by the ISD.
15. Aerospace described the scope of their testing in section 1.3 of the Wired Test Report as stated below:

> The test results reported in this document provide insight into AMF's MMN interference mitigation capabilities, and their performance under defined test parameters and assumptions (see Section 2). While the tests demonstrate compatibility under the conditions described herein, they do not guarantee electromagnetic compatibility with other signals or under conditions that are significantly different than the test conditions. In particular, the tests were performed in a wired environment and do not encompass

additional effects that may be encountered in wireless environments namely: 1) dynamic fading of interfering signals; 2) multipath channels between the MCU and ISDs; and 3) variable values for tissue loss. To account for possible fading link-loss, a fixed 20 [dB] fade margin has been built into the test setup.

The tests in this report do not endorse or qualify the AMF MMN system as being suitable for biological applications.

The tests were performed using MMN firmware version 2.0.00-beta25 and MCU FGPA version 59.

Based on the scope limitations of the Aerospace wired test stated above, if testing is performed in the future, radiated tests of the interference mitigation techniques should be included. The radiated tests would simulate the wireless environment whereby, the ISDs are embedded and the MMN and incumbent C-E systems are operating in a controlled wireless environment, such as an anechoic chamber.

16. The test results provided by AMF in response to the recommendations provided in JSC-10-058 to ensure the effectiveness of the MMN interference mitigation techniques were reviewed and found to be adequate. In addition, test results and data used to validate the body loss used in the analysis were also found to be adequate. No additional testing is recommended. If the MMN firmware or MCU FPGA is modified, subsequent testing should be performed to confirm that the interference mitigation techniques are not adversely affected.

Alfred Mann Foundation (AMF)
Medical Micropower Network (MMN)
WIRED TEST REPORT

November 3, 2010
version 0.61

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DEFINITIONS & ABREVIATIONS

ADC	Analog-to-digital converter
AMF	Alfred Mann Foundation
ARD	Airborne Radar Signal
AWG	Arbitrary Waveform Generator
BB	Base Band
BW	Bandwidth
CH	Channel
EMG	Electromyography
EPLRS	Enhanced Position Location Reporting System
fc	Carrier Frequency
FM	Frequency Modulation
fs	Sampling Frequency
FSK	Frequency Shift Keying
ISD	Interactive system device
MCU	Master Control Unit
MMN	Medical Micropower Network
MSK	Minimum-shift keying
PAR	Peak-to-average ratio
QPSK	Quadrature Phase Shift Keying
RAD	Ground Radar Signal
RF	Radio Frequency
RMS	Root mean square
SINR	Signal-to-interference plus noise ratio
SNR	Signal-to-noise ratio
SSB	Single Side Band
TDMA	Time Division Multiple Access
WDB	Wideband Signal

1. Introduction

1.1. Background

The Alfred Mann Foundation (AMF) has created a Medical Micropower Network (MMN) System for planned operation at UHF (413 to 456 MHz) using miliwatt power levels. The system has a central controller (Master Control Unit, MCU) that operates in a star-network, communicating via UHF with a an ensemble of smaller, less complex devices called interactive system devices (ISDs) as illustrated in Figure 1. The majority of the ISDs will be implanted in the human body. Their function is either to sense EMG (electromyography) signals or to deliver electrical stimulation pulses for functional rehabilitation or therapeutic purposes. The human skin acts as a natural RF attenuator and filter, allowing a simpler architecture for the ISDs. Since the system is planned to operate in an environment with incumbent RF user signals, the MCU has been designed with mitigation features to accommodate the expected interference from these users. These interference mitigation methods include the MMN System's ability to (a) excise narrowband incumbent signals on a spectral basis; (b) dynamically change channels without suspending critical functions; and (c) switch to a "graceful shutdown" mode in a scenario of complete loss of service of the communications link between the MCU and the ISDs. In addition, the MCU is designed to sense the RF environment and adapt its operating channel in order to avoid interfering with incumbent users.

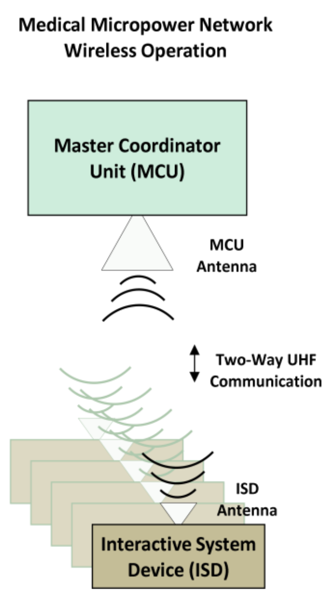

Figure 1. MMN Wireless Network

This report summarizes the results from a study, performed at The Aerospace Corporation, of a wired model of the system in Figure 1. The wired model, shown in Figure 2, is used to simplify the calibration and characterization of the MMN network and to evaluate performance on an additive white-Gaussian noise channel. To model some fading effects (losses) a 20 [dB] fade margin has been built into the wired setup. The MMN system, supplied by the AMF, was exposed to a variety of signals that can be found in the frequency band of operation. Signal types have been selected from those licensed for operation in the UHF bands listed above. The description of these signals can be found in Section 3.2. The test was automated for repeatability, and consists of subjecting a model MMN star network to interfering signals while monitoring the MCU's data link with the different interactive system devices. Throughout the different tests performed, the power of the calibrated interfering signals was incrementally increased in level forcing the MCU to mitigate the sensed interference.

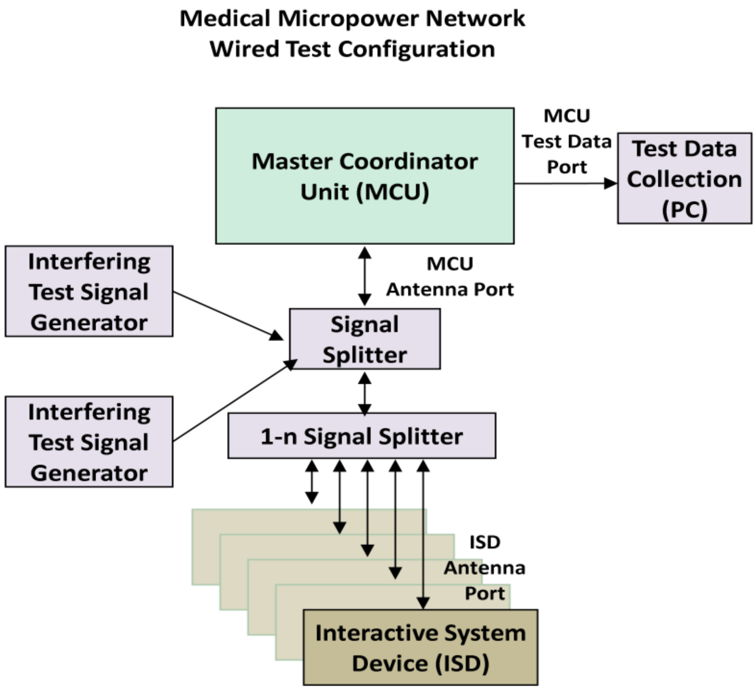

Figure 2. Wired Model of MMN

1.2. Goal

Tests were carried out by The Aerospace Corporation, El Segundo, CA, to characterize the MMN interference mitigation methods built into the MMN System to allow the MMN System to operate in a high-powered system environment, specifically in the presence of land mobile systems and radiolocation systems. The systems of interest typically operate in the 410 – 456 [MHz] frequency band.

Specifically, the tests outlined in this report were designed to evaluate the following,

- MMN system's ability to ***operate*** in presence of incumbent users under specific conditions described in Section 1.3
    - MCU's ability to spectrally excise narrowband incumbent users.
    - The ability of the system to change channels without suspending critical functions.
    - The ability of the system to gracefully shutdown in a communication link service-loss scenario.
- MCU ability to sense signal level of incumbent users in order to avoid MMN system interfering with them

1.3. Scope

The statement of work specifies that tests of AEMF hardware to evaluate operation in realistic RF environments and to determine thresholds and operational characteristics will be performed at The Aerospace Corporation.

The test results reported in this document provide insight into AMF's MMN interference mitigation capabilities, and their performance under defined test parameters and assumptions (see Section 2). While the tests demonstrate compatibility under the conditions described herein, they do not guarantee electromagnetic compatibility with other signals or under conditions that are significantly different than the test conditions. In particular, the tests were performed in a wired environment and do not encompass additional effects that may be encountered in wireless environments, namely: 1) dynamic fading of interfering signals; 2) multipath channels between the MCU and the ISDs; and 3) variable values for tissue loss. To account for possible fading link-losses, a fixed 20 [dB] fade margin has been built into the test setup.

In this report, the definition of an operational MMN system is the state of the network such that all the interactive system devices (IDSs) are being tracked, which means that the links are good enough for communication according to the MCU's assessment. Determining suitability of the link quality for the target application is out of the scope of this report. The tests in this report do not endorse or qualify the AMF MMN system as being suitable for biological applications.

The tests were performed using MMN firmware version 2.0.00-beta25 and MCU FPGA version 59.

1.4. Summary of Results

The tests conducted so far verify that the AMF MMN System performs according to its specifications (for the wired testing conditions described in Section 1.3) and is able to:

- Operate in presence of incumbent users under the considerations of Section 1.3.
    - MMN can spectrally excise narrowband incumbent users
    - MMN is able to change channels without suspending clinical functions
    - MMN is able to gracefully shutdown in a communication link service-loss scenario
- MCU is able to sense the signal level of incumbent users in order to avoid MMN system interfering with them by successfully changing channels.

The next section provides details of the testing conditions. Detailed test results are presented in Section 3.

2. Test Setup

2.1. Introduction

In order to evaluate the performance of the MMN network in the 412-456 [MHz] band, a wired simulation of the frequency band of interest was generated. An initial study was performed where documentation from the National Telecommunications and Information Administration (NTIA) [1] and the Telecommunications Industry Association (TIA) [2] was used as reference to evaluate signals present in this band. The technical description of these signals can be found in Section 3.2.

All of the signals used for the MMN evaluation were digitally-generated in a personal computer using Matlab®. As shown in Figure 3, these signals were uploaded to a pair of arbitrary waveform generators (AWG) and up-converted to the system's carrier frequency. This methodology enabled the generation of a large number of different signals within the band of interest. One signal generator was used to inject signals into the channel being tested, while the second AWG was used to simulate interferers on the other three available channels within the band of interest.

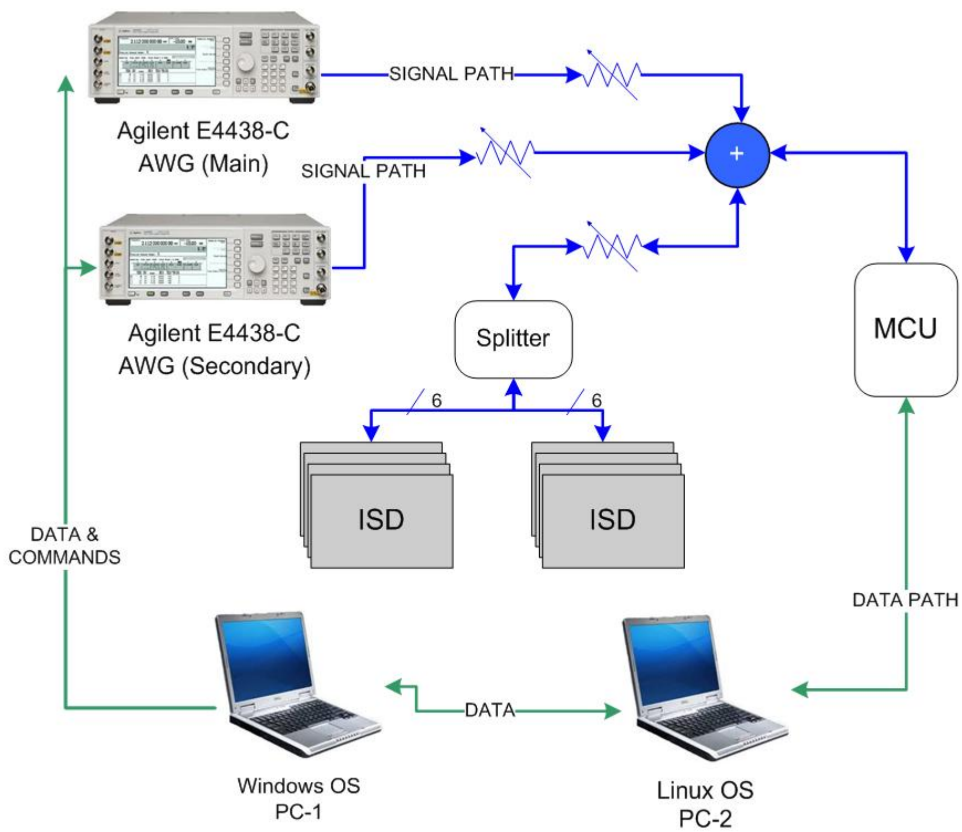

Figure 3. System Diagram

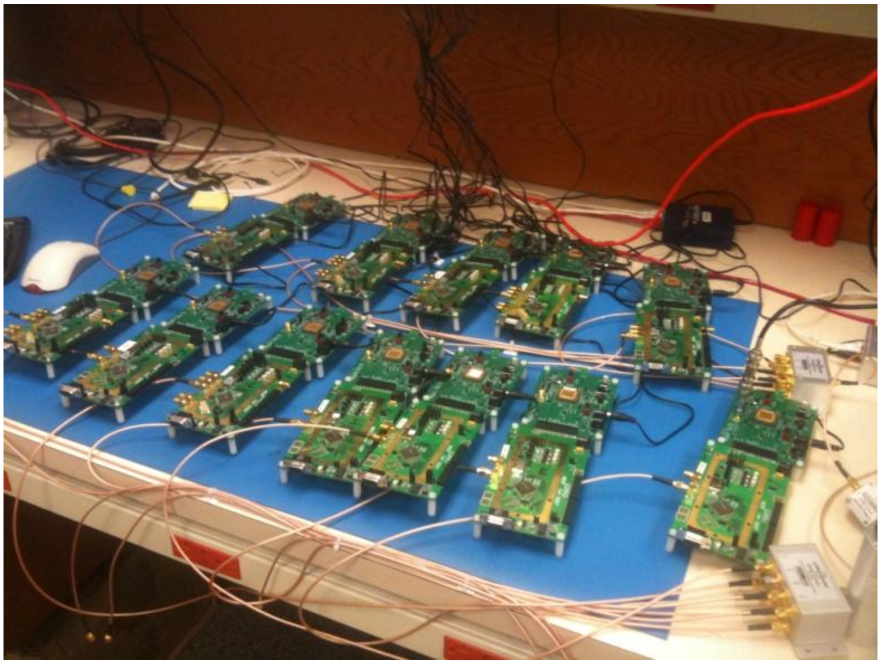

Figure 4. AMF Wired ISD Network

2.2. System Description

A diagram of the system being evaluated is shown in Figure 3. The MCU is directly connected to a network of ISDs. Currently, twelve ISDs are connected to the MCU using a wired connection. The ISD network can be observed in Figure 4. A pair of Agilent E-4438-C AWGs are used to simulate interference and the presence of other signals in the channel. As shown in Figure 3, each signal path has some type of signal-attenuation device used to simulate link losses typical of wireless channels.

The AWGs are connected using Internet Protocol (IP) via a local area network (LAN) to a personal computer (PC) running Windows XP operating system (OS). We will refer to this computer throughout the document as PC-1. This PC is responsible of generating the interference waveforms that are injected into the system, and of controlling the output power levels of each AWG. Similarly, the MCU is connected to a PC running Linux OS. We will refer to this computer as PC-2. This second PC interfaces with the MCU, reading and writing its registers and memory. All data resulting from an interaction between these two devices is stored in the hard drive of PC-2. Figure 5 shows PC-1 connected to two AWGs. The spectrum analyzer used to carry calibration measurements also appears in the figure.

In order to simulate a real channel scenario, our system works in such a way such that

- PC-1 determines the working environment: interferer types, power levels, etc.
- PC-2 will monitor the MCU and the ISD responses to these stimuli.
- System status information is transferred from PC-2 to PC-1 for data processing.

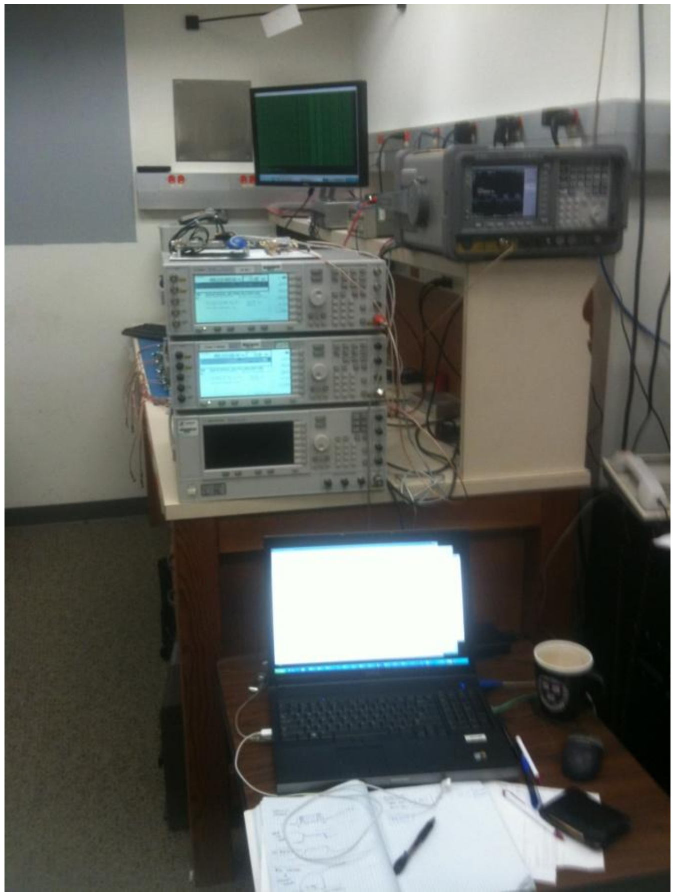

Figure 5. System setup

- **Spectrum Planning**

The AMF MMN system is planned to operate within four UHF channels described in Table 1 and illustrated in Figure 6. Therefore, the AWGs must generate interfering test signals covering the associated frequencies.

The final determination of the methodology to populate the frequency bands of interest with the desired signals was a compromise between:

- Sampling frequency (f_S) of the AWG: 96MHz→(48MHz band at the base band)
- Channel bandwidth
- Number of samples that the AWG can store: 16e6→(166msec total maximum record duration). Typical file sizes used are 2e6 samples long.
- Carrier Frequency: 456.31 [MHz]
- Analog performance of the AWG.

In order to maximize the time duration of the created waveforms, the smallest f_S was selected to 96 [MHz]. This allows the AWG to play a maximum of 16e6 (N_S) samples per I and Q component. This results in a maximum file duration of $N_S \,/\, f_S$ = 166msec.

The chosen sampling frequency allows the creation of a spectrum up to 48 [MHz] wide. In our case the bandwidth of interest is ~42 [MHz], which leaves a safe operational margin of 6 [MHz]. While calibrating our set up it was found that the AWG may exhibit amplitude variations in the first channel when a carrier of 413.9 [MHz] is chosen. To avoid inconsistent measurements, all of the base band signals were generated in the negative side of the spectrum and up-converted to f_c=456.31 [MHz].

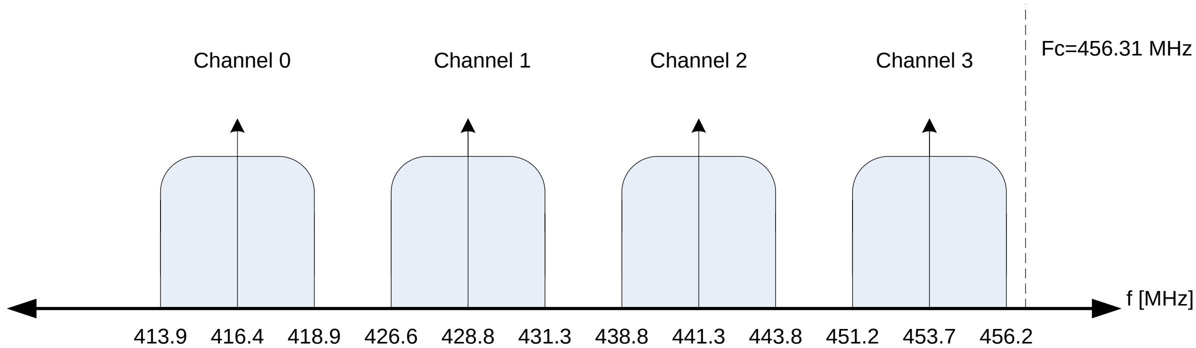

Figure 6. RF Spectrum Plan

CHANNEL	LEFT EDGE (MHz)	CENTER (MHz)	RIGHT EDGE (MHz)
1	413.9	416.4	418.9
2	426.3	428.8	431.3
3	438.8	441.3	443.8
4	451.2	453.7	456.2

Table 1. MMN UHF Channels

2.3. System Calibration

Signal power was measured throughout the RF chain from the AWGs to the MCU. To determine its output power, the AWG computes the root mean square (RMS) power of the transmitted signal and normalizes its output to that value. However, it was noted that the output power measured by the spectrum analyzer in the band, did not necessarily correspond to the power settings of the AWGs. This is due to the fact that the arbitrary waveforms loaded into the AWG have different peak-to-average-ratios (PAR). Also some scaling factors are used during file generation to guarantee that the digital-to-analog-converter (DAC) do not saturate This section explains the methodology used to consider these losses and to properly calibrate the MMN system.

The system set-up diagram shown in Figure 8 is a detailed version of the illustration in Figure 3.

In order to measure the losses on the network, measurements at different points, such as A in Figure 8 were taken.

The set of ZX76-31R5 variable attenuators is controlled using PC-1. These attenuators are used to control the level of interference that is injected to the MMN. The set of JFW 50DR-001 variable attenuators were set to a fixed value and are used to model typical losses in the communication link. A spectrum analyzer is connected to one of the two output ports of a ZFSC-2-1W splitter in order to capture the same signal levels that the MCU is exposed to. Figure 7 shows the sample case where the MCU is present on channel 0 while 10 FSK interferers are present on channel 1, and 5-FSK interferers appear on channels 2 and 3.

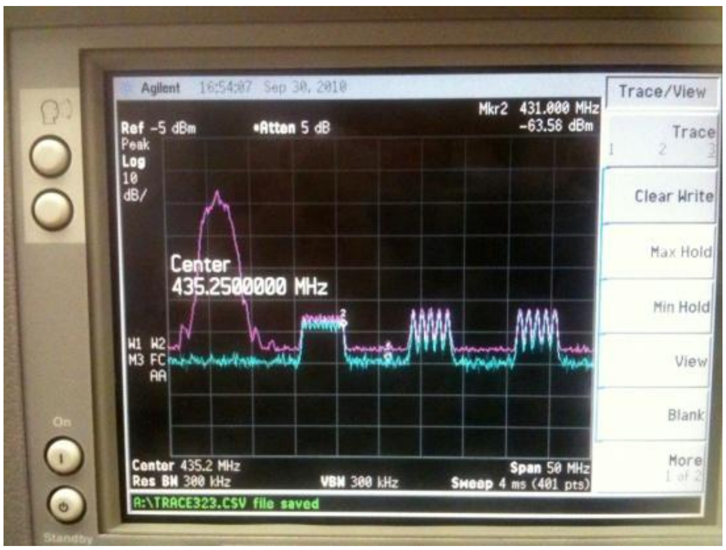

Figure 7. MCU on Channel 0 with interference on secondary channels

The following tables (Table 2 through Table 5) show the power values measured, and the assumed losses on each device in the MMN. A single FSK tone centered in channel 0, and an un-modulated tone were used for the measurements in Table 2 and Table 3. The end-to-end losses shown in Table 4, were measured on all operating channels using an un-modulated tone placed in the center of the channel. For all cases, the power measurement was averaged 50 times using a measuring bandwidth of between 30 and 50 [kHz].

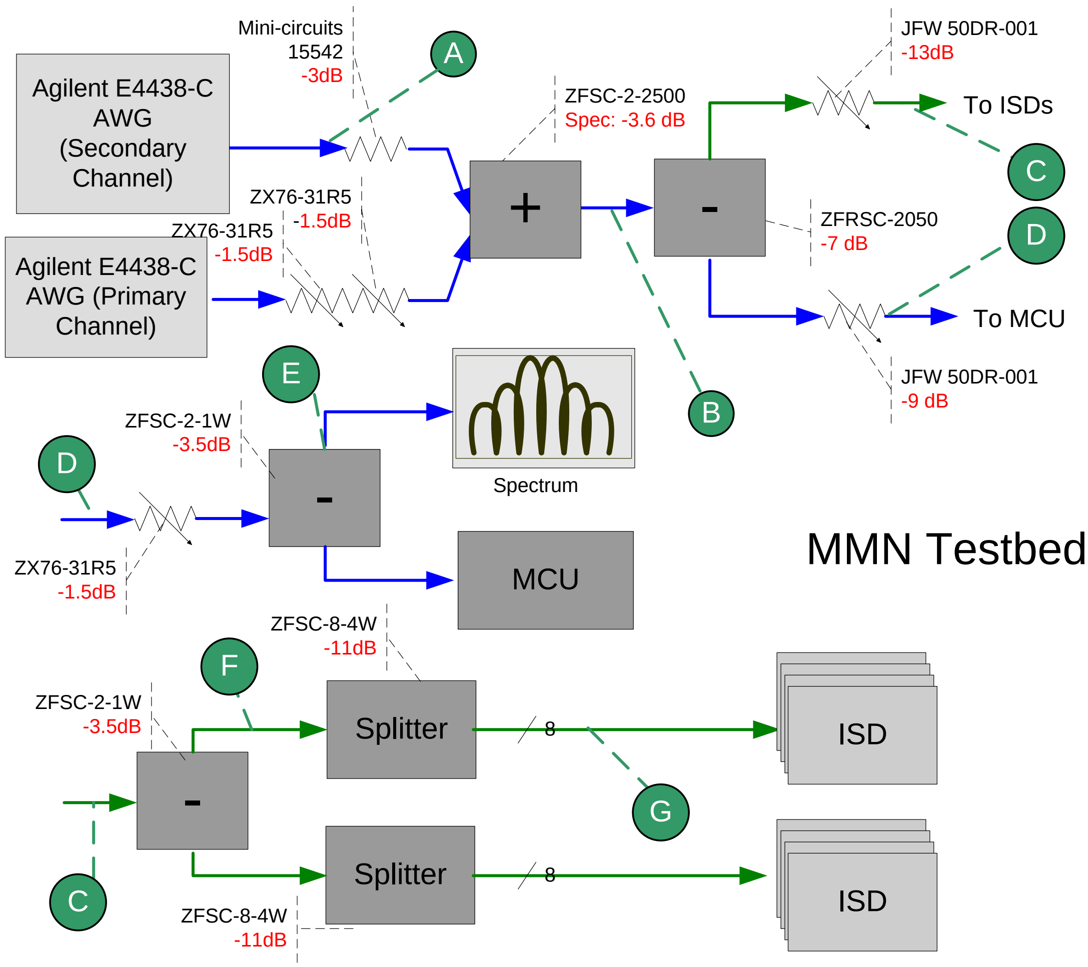

Figure 8 . MMN Connection Diagram

Results in Table 3 show that the measured insertion losses on the different instruments used are within the manufacturer's specifications.

All signals used for the test evaluation in this report were generated in software and uploaded to the signal generator. For a case where, for example, five signals co-exist on the same channel, the Matlab script creates each individual signal and combines all five into a single waveform. Before the waveform is uploaded, the power on each of the four channels is normalized. Also, some additional signal-scaling may be added to prevent the digital-to-analog converter from saturating. In order to assess the exact power going into the MMN network, the difference between the reported power at the signal generator and the power measured at its output is measured for all signals of interest. These values are reported in Table 5.

Probe Point	Signal Generator	A	B	C	D	E	F	G
FSK: Signal Power [dBm]	-20	-29.80	-36.50	-56.80	-52.80	-59.10	-60.50	-70.60
Tone: Signal Power [dBm]	-20	-20.46	-27.00	-47.44	-43.30	-49.91	-51.16	-61.46

Table 2. Signal Power Calibration Measurement

Probe Point	B-A ZFSC-2-2500 + MC-15542	C-B JFW 60DR-001 @13 + ZFRSC-2050	D-B JFW 60DR-001 @9+ ZFRSC-2050	E-D ZFSC-2-1w + ZX76-31R5	F-C ZFSC-2-1W	G-F ZFSC-8-4-W	**G-A** ISD Loss	E-A MCU Loss
FSK: Loss [dB]	-6.70	-20.30	-16.30	-6.30	-3.70	-10.10	-40.80	-29.30
Tone: Loss [dB]	-6.54	-20.44	-16.30	-6.61	-3.72	-10.30	-41.00	-29.45

Table 3. Calibration of power losses on the MMN network

END-TO-END LOSS	CHANNEL 0	CHANNEL 1	CHANNEL 2	CHANNEL 3
Loss @ MCU [dB]	-29.45	-29.75	-29.60	-30.16
Loss @ ISDs [dB]	-41.00	-41.40	-41.50	-41.50

Table 4. End-to-end losses per channel

RMS POWER LOSS (dB) @ (A)				
	CH0	**CH1**	**CH2**	**CH3**
FSK	-9.8	-8.5	-8.2	-7.8
FM	-9.8	-8.5	-8.1	-7.5
RAD	-9.60	-8.30	-8.00	-7.73
ARB	-10.30	-11.50	-11.20	-12.20
WDB	-7.30	-5.95	-5.70	-5.40
EPLRS	N/A	-5.50		
EPLRS (MSK)	N/A	-5.50		
SigGen to MCU	-29.45	-29.75	-29.60	-30.16

Table 5. RMS Power loss for all signals

2.4. Link signal-to-noise ratio (SNR) calculations

The system shown in Figure 8 was setup with attenuation values that would simulate realistic path-loss conditions of the medical device. Let us first define a number of quantities:

P_{MCU} : Transmit power at MCU = 0 [dBm]

P_{ISD} : Transmit power at ISD = -14 [dBm]

N_0 : Ambient noise PSD = -204 [dBW/Hz] = -174 [dBm/Hz]

B : Channel bandwidth = 5 [MHz] = 67 [dB-Hz]

NF_{ISD} : Noise figure at ISD receiver = 14 [dB]

NF_{MCU} : Noise figure at MCU receiver = 11 [dB]

G_{down} : Total path gain from MCU to ISD = -57 [dB] (using Figure 8 and note 1 below)

G_{up} : Total path gain from ISD to MCU = -48.5 [dB] (using Figure 8)

The received SNR at MCU is calculated in dB as follows

$$SNR_{up} = G_{up} + P_{ISD} - N_0 - B - NF_{MCU} = 33.5 \text{ [dB]}$$

The received SNR at the ISD is calculated in dB as follows

$$SNR_{down} = G_{down} + P_{MCU} - N_0 - B - NF_{ISD} = 36 \text{ [dB]}$$

Notes

1) The asymmetry $G_{up} \neq G_{down}$ of the total path gain is due to the presence of an attenuation of 8.5[dB] present on the receive path of the ISD board.
2) The nominal attenuation due to propagation through tissue (or phantom) is assumed to be around 20 [dB].
3) As a result, (48.5 – 20) = 28.5 [dB] is attributed to path-loss and antenna losses. At 440 [MHz], the 1 [m] free-space path loss is around 25 [dB].
4) The NF_{ISD} = 14 [dB] is not the actual noise figure of the ISD device which is around 8 [dB] in practice. The higher noise figure in the setup is due to the tuning of the matching networks on the AMF supplied ISD board. AMF said that the tuning was done to minimize gain differences across channels.
5) The power output of the ISD transmitter is nominally 0 dBm. The 14 dB attenuation is present due to matching network designed to provide relatively constant response across the band, which is a feature of the test board to facilitate testing.

2.5. Link signal-to-interference plus noise ratio (SINR) calculations

From the output of the AWG to the ISD, using Figure 8, we have path gain of -41.1 [dB]. If we include the 8.5 [dB] attenuation going into the ISD board, this results in a total path gain of $G_{AWG \to ISD}$ = -49.6 [dB]. From the output of the AWG to the MCU we have a path gain of $G_{AWG \to MCU}$ = -27.6 [dB]. The additional 22 [dB] extra attenuation that the interferer suffers going to the ISD is attributed to the tissue propagation losses.

Let the (average) interference power at the output of the AWG be denoted as *I* then the uplink SINR (*using quantities defined in linear scale*) is calculated as

$$SINR_{up} = \frac{G_{up} \, .P_{ISD}}{N_0.B.NF_{MCU} \; + \; G_{AWG \to MCU}.I}$$

Similarly the downlink SINR is calculated as

$$SINR_{down} = \frac{G_{down} \, .P_{MCU}}{N_0.B.NF_{ISD} \; + \; G_{AWG \to ISD}.I}$$

If we use the values of gains and powers as discussed in the previous section, we may plot the SINR vs. interference power *I* as shown in Figure 9 below. This figure shows that for larger interference powers the downlink has around 27.5 [dB] more margin than the uplink. Note that the MCU employs spectral excision for narrowband interference and as a result can operate at much lower SINR (i.e. the SINR post-excision will usually be much higher).

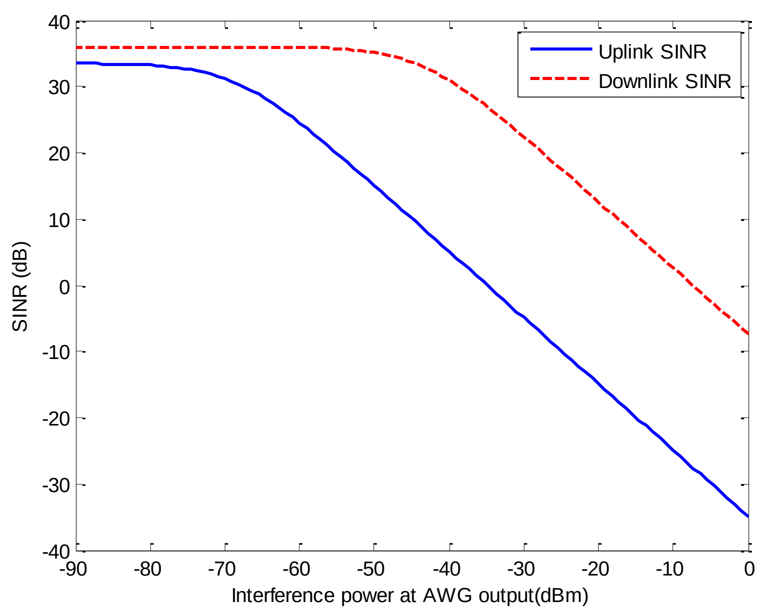

Figure 9. SNR vs. Interference Power

3. Wired Measurements

3.1. Signal Generation:

Signals are generated in a way such that the average RMS power on a given channel is kept constant, independently of the number of signals per channel. For example,

- A Single FSK Signal has RMS Power: 0 [dBm]
- Five FSK signals have a channel-RMS overall power of 0 [dBm]. Each of these signals, has an individual RMS power of 0-10*log10(5) = -7 [dBm].

3.2. Signals Tested

- **Frequency Shift Key (FSK) Signals**

  Signal Specification (from TIA spec P.25 [2])
    - Channel spacing: 12.5[kHz],
    - Frequency Deviation: +1800, +600, -600, -1800[Hz],
    - Symbol Rate: 4800 [sym/sec]
    - Users: Amateur Radio, Land Mobile Radio (LMR)
    - Band: 410-460MHz

- **Analog Frequency Modulation (FM) Signals**

  Signal Specification (from TIA spec P.25 [2])
    - Channel spacing: 12.5/25 [kHz]
    - Users: Amateur Radio, older LMR systems
    - Band: 410-460[MHz]

- **Airborne RADAR**

  Signal Specification (from NTIA document [1])
    - 8us pulses
    - 2 [kHz] repetition rate
    - Users: Military
    - Band: 420-450[MHz]

- **Ground RADAR**

  Signal Specification (from NTIA document [1])

  - Search: 100-350[kHz] chirp,
  - Track: 1 or 5 [MHz]
  - 41Hz repetition rate
  - Users: Military
  - Band: 420-450 [MHz]

- **Enhanced Position Location Reporting System (EPLRS)**
  - 3MHz Spread Spectrum, 8 channels
  - Hops around channels using synchronous TDMA, 2ms or 4ms timeslots.
  - Users: Military
  - Channels centered at 425.75, 428.75, 431.75, 434.75, 437.75, 440.75, 443.75, 446.75[MHz].

- **Amateur TV**
  - A random squared root-raised Cosine (256-tap) wideband signal was used to simulate amateur TV interference
  - Alpha = 0.35
  - BW: 6 [MHz]
  - Centered at the channel of interest

3.3. Tests Performed

i. Graceful Shutdown

Description:

Perform test (steps 1-8 below) for different interferers

1. Set operating band of MMN system to CH0.
2. Generate high level interferers above MMN system operating threshold on the other three channels. In effect, this blocks the MMN system from switching channels thus enabling efficient test for graceful shutdown
3. Generate interferer at CH1 center frequency with the maximum power for the given test and set a variable attenuator to its maximum level (-63 [dB]).
4. Decrease attenuation by .5 dB steps until eliminating the variable attenuation. The time at which the MMN begins the Graceful Shutdown procedure will be logged to a file.
5. Record interference power level and time to shutdown state. Record MCU transmit shutdown (*) time relative to interference injection time.
6. Repeat test and report minimum, maximum, and mean of interference power level, time to shutdown and time to MCU transmit shutdown.
7. Repeat steps 1 through 6 with operating channel set to CH1, CH2, and then CH3.
8. Repeat tests with different interferer combinations, with interferers uniformly spaced across the 5MHz channel bandwidth. Repeat steps 1-7 for each case.

Test Objective

- Evaluate the threshold signal-power level that causes the MCU to search for an alternate channel.
- Determine if the MCU correctly measures the interference power levels on all channels.
- In the event that all other possible channels are in use, determine whether the MCU can begin a graceful shutdown procedure.
- Evaluate the statistical variance of the different results and determine the expected power threshold value for a graceful shutdown procedure.

Observations

- The tests results reported in Table 6 and Table 7 show graceful shutdown results for narrowband FSK and FM signals on the main channel, and a different set of signals on the alternate channels. For all "Graceful Shutdown" tests, the fixed channel interference is set to a relatively high value to prevent the MCU from switching to an alternate channel and forcing it to shutdown.

- Once the system begins a graceful shutdown procedure the following set of events occur:
  - MCU sends a command to the ISDs to begin a pre-programmed shutdown
  - Stimulation from the MCU to the ISDs is turned off
  - MCU Transmitter is turned off
  - Communication with ISDs is lost

- The tables below (Table 6 and beyond) show the following properties of the system:
  - Channel being evaluated
  - Number of repetitions for each test
  - Type and Number of signals per channel
  - Link Losses in the system
    - Signal Loss: power loss due to signal scaling for the signal in the channel being tested
    - Interference Loss: power loss due to signal scaling for the signals present on the secondary channels being tested
    - Overall system attenuation, as measured in Table 5
  - Fixed Channel Interference Power: fixed level for the signals present on alternative channels
  - Signal Channel Power: detected threshold signal-power of the channel being studied that triggers a graceful shutdown procedure
  - Individual Interference Power: For narrowband signals, the power of each individual component is equal to *Power(Channel) – 10*log$_{10}$(Number of Signals in the Channel)*. For wideband signals (EPLRS, Analog Television) no normalization is used.
  - Individual Signal Power: For narrowband signals, the power of each individual signal in the channel of interest is equal to *Power(Channel) – 10*log$_{10}$(Number of Signals in the Channel)*. For example, the first set of results in Table 6, use a single FSK tone in the channel of interest. Therefore "Signal Channel Power"="Individual Signal Power". For the second set, where five FSK tones are uniformly spaced within the band of interest:

"Individual Signal Power" = "Signal Channel Power" – 6.99 [dB]. For both cases the AWGs are set at a given power, for example 0 [dBm]. However, since the energy of each channel is normalized, for the case of five FSK signals, the power of each individual signal of the set will be -6.99 [dBm].

- The duty cycle present in radar signals results in the MCU being able to operate in the same channel as the interference. For the case of multiple radar signals present in the same channel, the increase in the effective duty cycle triggered, in some cases, shutdown events. However systematic and repeatable triggering of shutdown procedure under radar stimulus was not observed with regularity.

- Although it has been consistently observed (while testing) that there are very few data errors reported, both in the uplink and downlink channels of the MCU, the current tests do not focus on characterizing the bit error rate performance of the communication channel. Under some relatively high-level interference conditions, some errors in the communication channel were observed, prior to a channel-change or shutdown procedure.

Test Summary

- The threshold signal-power level that triggers a graceful shutdown procedure is between -62.9 to -59 [dBm] for FSK and FM signals
- The MCU systematically succeeds in measuring the presence of interference on alternative channels. Due to the high power present in these bands (signal power of interference signals is typically set above -47 [dBm]), a graceful shutdown procedure is triggered.
- The MCU can begin a graceful shutdown procedure
- The results have a variance of about 1 [dB], which is within the measurement error margin.

Graceful Shutdown																								
Test Chan.	Rep.	CH0		CH1		CH2		CH3		Link Loss [dB]			Fixed Channel Interference Power (RMS) [dBm]	Signal Channel Power (RMS) [dBm]			Individual Interference Power [dBm]			Individual Signal RMS Power [dBm]		
		Signal	No.of Signals	Signal	No.of Signals	Signal	No.of Signals	Signal	No.of Signals	Signal	Interf.	Atten.		Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
0	5	**FSK**	**1**	FSK	5	FSK	5	FSK	5	-9.80	-8.17	-29.45	-37.62	-62.45	-62.75	-62.25	-44.61	-44.61	-44.61	-62.45	-62.75	-62.25
1	5	FSK	5	**FSK**	**1**	FSK	5	FSK	5	-8.50	-8.60	-29.75	-38.35	-61.45	-61.75	-61.25	-45.34	-45.34	-45.34	-61.45	-61.75	-61.25
2	5	FSK	5	FSK	5	**FSK**	**1**	FSK	5	-8.20	-8.70	-29.60	-38.30	-60.50	-60.80	-60.30	-45.29	-45.29	-45.29	-60.50	-60.80	-60.30
3	5	FSK	5	FSK	5	FSK	5	**FSK**	**1**	-7.80	-8.83	-30.16	-38.99	-59.76	-59.96	-59.46	-45.98	-45.98	-45.98	-59.76	-59.96	-59.46
0	4	**FSK**	**5**	FSK	5	FSK	5	FSK	5	-9.80	-8.17	-29.45	-37.62	-55.38	-55.75	-55.25	-44.61	-44.61	-44.61	-62.36	-62.74	-62.24
1	5	FSK	5	**FSK**	**5**	FSK	5	FSK	5	-8.50	-8.60	-29.75	-38.35	-54.65	-54.75	-54.25	-45.34	-45.34	-45.34	-61.64	-61.74	-61.24
2	5	FSK	5	FSK	5	**FSK**	**5**	FSK	5	-8.20	-8.70	-29.60	-38.30	-53.00	-53.80	-52.30	-45.29	-45.29	-45.29	-59.99	-60.79	-59.29
3	5	FSK	5	FSK	5	FSK	5	**FSK**	**5**	-7.80	-8.83	-30.16	-38.99	-52.26	-52.46	-51.96	-45.98	-45.98	-45.98	-59.25	-59.45	-58.95
0	4	**FSK**	**20**	FSK	10	FSK	5	FSK	5	-9.80	-8.17	-29.45	-37.62	-50.25	-50.25	-50.25	-47.62	-47.62	-47.62	-63.26	-63.26	-63.26
1	4	FSK	10	**FSK**	**20**	FSK	5	FSK	5	-8.50	-8.60	-29.75	-38.35	-49.50	-49.75	-49.25	-45.34	-45.34	-45.34	-62.51	-62.76	-62.26
2	4	FSK	10	FSK	5	**FSK**	**20**	FSK	5	-8.20	-8.70	-29.60	-38.30	-48.43	-48.80	-47.80	-45.29	-45.29	-45.29	-61.44	-61.81	-60.81
3	4	FSK	10	FSK	5	FSK	5	**FSK**	**20**	-7.80	-8.83	-30.16	-38.99	-49.96	-49.96	-49.96	-45.98	-45.98	-45.98	-62.97	-62.97	-62.97
0	4	**FSK**	**1**	WDB	1	WDB	1	WDB	1	-9.80	-5.68	-29.45	-35.13	-62.25	-62.25	-62.25	-35.13	-35.13	-35.13	-62.25	-62.25	-62.25
1	4	WDB	1	**FSK**	**1**	WDB	1	WDB	1	-8.50	-6.13	-29.75	-35.88	-61.63	-61.75	-61.25	-35.88	-35.88	-35.88	-61.63	-61.75	-61.25
2	4	WDB	1	WDB	1	**FSK**	**1**	WDB	1	-8.20	-6.22	-29.60	-35.82	-60.43	-60.80	-60.30	-35.82	-35.82	-35.82	-60.43	-60.80	-60.30
3	4	WDB	1	WDB	1	WDB	1	**FSK**	**1**	-7.80	-6.32	-30.16	-36.48	-59.71	-59.96	-59.46	-36.48	-36.48	-36.48	-59.71	-59.96	-59.46
0	4	**FSK**	**5**	WDB	1	WDB	1	WDB	1	-9.80	-5.68	-29.45	-35.13	-55.63	-55.75	-55.25	-35.13	-35.13	-35.13	-62.61	-62.74	-62.24
1	4	WDB	1	**FSK**	**5**	WDB	1	WDB	1	-8.50	-6.13	-29.75	-35.88	-54.88	-55.25	-54.25	-35.88	-35.88	-35.88	-61.86	-62.24	-61.24
2	4	WDB	1	WDB	1	**FSK**	**5**	WDB	1	-8.20	-6.22	-29.60	-35.82	-53.18	-53.30	-52.80	-35.82	-35.82	-35.82	-60.16	-60.29	-59.79
3	4	WDB	1	WDB	1	WDB	1	**FSK**	**5**	-7.80	-6.32	-30.16	-36.48	-52.34	-52.46	-51.96	-36.48	-36.48	-36.48	-59.32	-59.45	-58.95

Table 6. Graceful Shutdown: FSK

Graceful Shutdown																							
Test Chan.	Rep.	CH0		CH1		CH2		CH3		Link Loss [dB]			Fixed Channel Interference Power (RMS) [dBm]	Signal Channel Power (RMS) [dBm]			Individual Interference Power [dBm]			Individual Signal RMS Power [dBm]		
		Signal	No.of Signals	Signal	No.of Signals	Signal	No.of Signals	Signal	No.of Signals	Signal	Interf.	Atten.		Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
0	5	**FM**	**1**	FM	1	FM	1	FM	1	-9.80	-8.03	-29.45	-37.48	-62.15	-62.25	-61.75	-37.48	-37.48	-37.48	-62.15	-62.25	-61.75
1	5	FM	1	**FM**	**1**	FM	1	FM	1	-8.50	-8.47	-29.75	-38.22	-61.45	-61.75	-61.25	-38.22	-38.22	-38.22	-61.45	-61.75	-61.25
2	5	FM	1	FM	1	**FM**	**1**	FM	1	-8.10	-8.60	-29.60	-38.20	-60.40	-60.70	-60.20	-38.20	-38.20	-38.20	-60.40	-60.70	-60.20
3	5	FM	1	FM	1	FM	1	**FM**	**1**	-7.50	-8.80	-30.16	-38.96	-59.06	-59.66	-58.66	-38.96	-38.96	-38.96	-59.06	-59.66	-58.66
0	5	**FM**	**5**	FM	1	FM	1	FM	1	-9.80	-8.03	-29.45	-37.48	-55.35	-55.75	-55.25	-37.48	-37.48	-37.48	-62.34	-62.74	-62.24
1	5	FM	1	**FM**	**5**	FM	1	FM	1	-8.50	-8.47	-29.75	-38.22	-54.75	-55.25	-54.25	-38.22	-38.22	-38.22	-61.74	-62.24	-61.24
2	5	FM	1	FM	1	**FM**	**5**	FM	1	-8.10	-8.60	-29.60	-38.20	-53.30	-53.70	-53.20	-38.20	-38.20	-38.20	-60.29	-60.69	-60.19
3	5	FM	1	FM	1	FM	1	**FM**	**5**	-7.50	-8.80	-30.16	-38.96	-52.46	-52.66	-52.16	-38.96	-38.96	-38.96	-59.45	-59.65	-59.15
0	4	**FM**	**1**	FSK	1	FSK	1	FSK	1	-9.80	-8.17	-29.45	-37.62	-62.38	-62.75	-62.25	-37.62	-37.62	-37.62	-62.38	-62.75	-62.25
1	4	FSK	1	**FM**	**1**	FSK	1	FSK	1	-8.50	-8.60	-29.75	-38.35	-61.75	-62.25	-61.25	-38.35	-38.35	-38.35	-61.75	-62.25	-61.25
2	4	FSK	1	FSK	1	**FM**	**1**	FSK	1	-8.10	-8.70	-29.60	-38.30	-60.20	-60.70	-59.70	-38.30	-38.30	-38.30	-60.20	-60.70	-59.70
3	4	FSK	1	FSK	1	FSK	1	**FM**	**1**	-7.50	-8.83	-30.16	-38.99	-59.29	-59.66	-59.16	-38.99	-38.99	-38.99	-59.29	-59.66	-59.16
0	4	**FM**	**5**	FSK	1	FSK	1	FSK	1	-9.80	-8.17	-29.45	-37.62	-55.25	-55.75	-54.75	-37.62	-37.62	-37.62	-62.24	-62.74	-61.74
1	4	FSK	1	**FM**	**5**	FSK	1	FSK	1	-8.50	-8.60	-29.75	-38.35	-54.75	-54.75	-54.75	-38.35	-38.35	-38.35	-61.74	-61.74	-61.74
2	4	FSK	1	FSK	1	**FM**	**5**	FSK	1	-8.10	-8.70	-29.60	-38.30	-53.20	-53.20	-53.20	-38.30	-38.30	-38.30	-60.19	-60.19	-60.19
3	4	FSK	1	FSK	1	FSK	1	**FM**	**5**	-7.50	-8.83	-30.16	-38.99	-52.16	-52.16	-52.16	-38.99	-38.99	-38.99	-59.15	-59.15	-59.15
0	4	**FM**	**1**	WDB	1	WDB	1	WDB	1	-9.80	-5.68	-29.45	-35.13	-62.13	-62.25	-61.75	-35.13	-35.13	-35.13	-62.13	-62.25	-61.75
1	4	WDB	1	**FM**	**1**	WDB	1	WDB	1	-8.50	-6.13	-29.75	-35.88	-62.00	-62.25	-61.75	-35.88	-35.88	-35.88	-62.00	-62.25	-61.75
2	4	WDB	1	WDB	1	**FM**	**1**	WDB	1	-8.10	-6.22	-29.60	-35.82	-60.45	-60.70	-60.20	-35.82	-35.82	-35.82	-60.45	-60.70	-60.20
3	4	WDB	1	WDB	1	WDB	1	**FM**	**1**	-7.50	-6.32	-30.16	-36.48	-59.41	-59.66	-59.16	-36.48	-36.48	-36.48	-59.41	-59.66	-59.16

Table 7. Graceful Shutdown. FM

Two types of interference have been used for the FM and FSK-test cases: FM& FSK interference (narrowband), and a wideband (WDB) interference that models analog television signals.

ii. *Channel Switching*

Description

Perform test (steps 1-7 below) for different interferers

1. Set operating band of MMN system to CH0. On the unused channels, generate uniformly spaced interferers of below switching threshold.
2. Generate interferer at CH1 center frequency with the maximum power for the given test and set a variable attenuator to its maximum level (-60 [dB]).
3. Decrease attenuation by .5 dB steps until eliminating the variable attenuation. The time at which the MMN begins the channel switching procedure will be logged to a file. When channel changes, record interference power level and time to channel change.
4. Repeat test and report PASS if all interactive system devices (IDSs) are in track and channel change ID corresponds to the best channel. Report minimum, maximum, and mean of interference power level and channel change time.
5. Repeat test and report minimum, maximum, and mean of interference power level, time to shutdown and time to MCU transmit shutdown.
6. Repeat steps 1 through 5 with operating channel set to CH1, CH2, and then CH3.
7. Repeat tests with different interferer combinations, with interferers uniformly spaced across the 5MHz channel bandwidth. Repeat steps 1-6 for each case.

Test Objective

- Evaluate the threshold signal-power level that causes the MCU to search for and switch to an alternative channel when the current operating channel is affected by interference.
- Evaluate the relationship between the signal characteristics and the channel-change threshold.
- Evaluate the relationship between the signal type and power in the alternative channels, and the detected threshold on the channel of interest

Observations

- These tables below show the following properties of the system:
  - Channel being evaluated
  - Number of repetitions for each test
  - Type and Number of Signals per channel
  - Link Losses in the system
    - Signal Loss: power loss due to signal scaling for the signal in the channel being tested
    - Interference Loss: power loss due to signal scaling for the signals present on the secondary channels being tested
    - Overall system attenuation, as measured in Table 5
  - Fixed Channel Interference Power: fixed level for the signals present on alternative channels
  - Signal Channel Power: detected threshold signal-power of the channel being studied that triggers a graceful shutdown procedure
  - Individual Interference Power: For narrowband signals, the power of each individual component is equal to *Power(Channel) – 10*log*$_{10}$*(Number of Signals in the Channel)*. For wideband signals (EPLRS, Analog Television) no normalization is used.
  - Individual Signal Power: For narrowband signals, the power of each individual signal in the channel of interest is equal to Power(Channel) - 10*log10(Number of Signals in the Channel). For example, the first set of results in Table 8 use a single FSK tone in the channel of interest. Therefore "Signal Channel Power"="Individual Signal Power". For the second set, where five FSK tones are uniformly spaced within the band of interest: "Individual Signal Power" = "Signal Channel Power" - 6.99 [dB].

Test Summary:

- The threshold signal-power level that triggers a channel change procedure is, in general, between -62.9 to -59 [dBm] for FSK and FM signals.
- The MCU systematically succeeds in measuring the presence of interference on alternative channels. Due to the low power present in these bands (signal power of interference signals is typically set below -47 [dBm]), a channel change procedure is triggered.
- The MCU can begin a channel change procedure
- The results have a variance of about 1 [dB], which is within the measurement error margin.

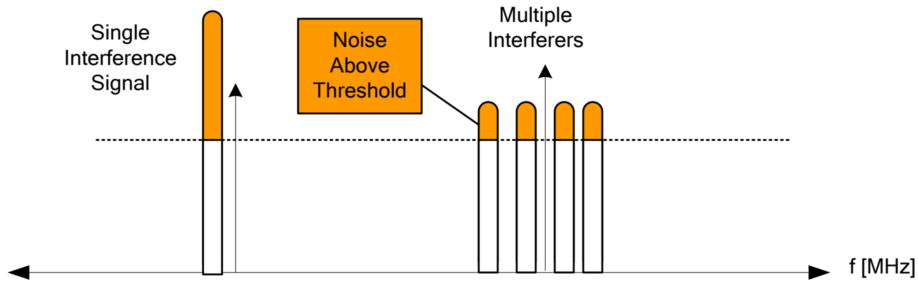

Figure 10. Noise Measurement

- Observations on FSK Channel Change:

For the cases of a single and five FSK signal in the channel of interest, the individual signal power that triggered a channel change procedure was between -62.6 and -59.7 [dBm]. These levels coincide with the ones obtained for graceful shutdown, and shown in Table 6. These results imply that once these signal levels are reached, the MCU decides to abandon the current channel due to the measured signal interference power on the current channel. If the power levels on the alternate channels are low enough to enable communication in the presence of interference, then a channel change occurs. If the interference levels are too high to guarantee a digital communication with a low BER, then a graceful shutdown procedure is triggered.

For the case of twenty FSK signals in the channel of interest, the signal level at which a channel change is triggered is 23 [dB] lower. The MCU triggers a channel change based on a different metric: the signal-to-noise ratio (SNR) in the current channel. The characteristics of a channel with twenty interferers is such that amount of excess noise in the channel is reached at an earlier level compared to a case with fewer signals. This concept is illustrated in Figure 10, where four interferers provide the same amount of noise as a single interference operating at a much higher power.

- Observations on FM Channel Change:

For all cases the individual signal-power that triggered a channel change procedure was between -62.6 and -59.7 [dBm]. These levels coincide with the ones obtained for graceful shutdown, and shown in Table 7.

These results imply that once these signal levels are reached, the MCU decides to abandon the current channel. If the power levels on the alternate channels are low enough to enable communication in the presence of interference, then a channel change occurs. If the interference levels are too high to guarantee a digital communication with a low BER, then a graceful shutdown procedure is triggered.

- Observations on Airborne Radar Channel Change:

For all cases the individual signal-power that triggered a channel change procedure was between -56.7 and -50.87 [dBm]. These levels are higher than in the case of FSK and FM signals that have a duty cycle of unity.

These results imply that the MCU has greater tolerance for signals of low duty cycles.

The higher variance observed in these results is also attributed to random signal effects caused by the duty cycle of the radar

- Observations on Ground Radar Channel Change:

The same conclusions for airborne radar apply. Results for the case of two ground radar signals coexisting in the same channel show a variance that is larger than usual.

Channel Change																					
Test Chan.	**Rep.**	**CH0**		**CH1**		**CH2**		**CH3**		**Link Loss [dB]**			**Fixed Channel Interference Power [dBm]**	**Signal Channel Power (RMS) [dBm]**			**Individual Interference Power [dBm]**			**Individual Signal Power [dBm]**	
		Signal	**No.of Signals**	**Signal**	**No.of Signals**	**Signal**	**No.of Signals**	**Signal**	**No.of Signals**	**Signal**	**Interf.**	**Atten.**		**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**
0	4	**FSK**	**1**	FSK	5	FSK	5	FSK	5	-9.80	-8.17	-29.45	-62.62	-62.63	-62.75	-62.25	-69.61	-69.61	-69.61	-62.63	-62.75	-62.25
1	4	FSK	5	**FSK**	**1**	FSK	5	FSK	5	-8.50	-8.60	-29.75	-63.35	-61.63	-61.75	-61.25	-70.34	-70.34	-70.34	-61.63	-61.75	-61.25
2	4	FSK	5	FSK	5	**FSK**	**1**	FSK	5	-8.20	-8.70	-29.60	-63.30	-60.55	-60.80	-60.30	-70.29	-70.29	-70.29	-60.55	-60.80	-60.30
3	4	FSK	5	FSK	5	FSK	5	**FSK**	**1**	-7.80	-8.83	-30.16	-63.99	-59.71	-59.96	-59.46	-70.98	-70.98	-70.98	-59.71	-59.96	-59.46
0	4	**FSK**	**5**	FSK	5	FSK	5	FSK	5	-9.80	-8.17	-29.45	-62.62	-55.63	-55.75	-55.25	-69.61	-69.61	-69.61	-62.61	-62.74	-62.24
1	4	FSK	5	**FSK**	**5**	FSK	5	FSK	5	-8.50	-8.60	-29.75	-63.35	-54.88	-55.25	-54.75	-70.34	-70.34	-70.34	-61.86	-62.24	-61.74
2	4	FSK	5	FSK	5	**FSK**	**5**	FSK	5	-8.20	-8.70	-29.60	-63.30	-53.30	-53.80	-52.80	-70.29	-70.29	-70.29	-60.29	-60.79	-59.79
3	4	FSK	5	FSK	5	FSK	5	**FSK**	**5**	-7.80	-8.83	-30.16	-63.99	-52.71	-52.96	-52.46	-70.98	-70.98	-70.98	-59.70	-59.95	-59.45
0	4	**FSK**	**20**	FSK	10	FSK	5	FSK	5	-9.80	-8.17	-29.45	-62.62	-72.75	-72.75	-72.75	-72.62	-72.62	-72.62	-85.76	-85.76	-85.76
1	4	FSK	10	**FSK**	**20**	FSK	5	FSK	5	-8.50	-8.60	-29.75	-63.35	-71.75	-71.75	-71.75	-70.34	-70.34	-70.34	-84.76	-84.76	-84.76
2	4	FSK	10	FSK	5	**FSK**	**20**	FSK	5	-8.20	-8.70	-29.60	-63.30	-71.30	-71.30	-71.30	-70.29	-70.29	-70.29	-84.31	-84.31	-84.31
3	4	FSK	10	FSK	5	FSK	5	**FSK**	**20**	-7.80	-8.83	-30.16	-63.99	-71.46	-71.46	-71.46	-70.98	-70.98	-70.98	-84.47	-84.47	-84.47

Table 8. FSK channel change

Channel Change																						
Test Chan.	Rep.	CH0		CH1		CH2		CH3		Link Loss [dB]			Fixed Channel Interference Power [dBm]	Signal Channel Power (RMS) [dBm]			Individual Interference Power [dBm]			Individual Signal Power [dBm]		
		Signal	No.of Signals	Signal	No.of Signals	Signal	No.of Signals	Signal	No.of Signals	Signal	Interf.	Atten.		Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
0	4	**FM**	**1**	FM	1	FM	1	FM	1	-9.80	-8.03	-29.45	-62.48	-62.38	-62.75	-62.25	-62.48	-62.48	-62.48	-62.38	-62.75	-62.25
1	4	FM	1	**FM**	**1**	FM	1	FM	1	-8.50	-8.47	-29.75	-63.22	-61.38	-61.75	-60.75	-63.22	-63.22	-63.22	-61.38	-61.75	-60.75
2	4	FM	1	FM	1	**FM**	**1**	FM	1	-8.10	-8.60	-29.60	-63.20	-60.00	-60.20	-59.70	-63.20	-63.20	-63.20	-60.00	-60.20	-59.70
3	4	FM	1	FM	1	FM	1	**FM**	**1**	-7.50	-8.80	-30.16	-63.96	-59.79	-60.16	-59.16	-63.96	-63.96	-63.96	-59.79	-60.16	-59.16
0	4	**FM**	**5**	FM	1	FM	1	FM	1	-9.80	-8.03	-29.45	-62.48	-55.25	-55.25	-55.25	-62.48	-62.48	-62.48	-62.24	-62.24	-62.24
1	4	FM	1	**FM**	**5**	FM	1	FM	1	-8.50	-8.47	-29.75	-63.22	-54.63	-55.25	-54.25	-63.22	-63.22	-63.22	-61.61	-62.24	-61.24
2	4	FM	1	FM	1	**FM**	**5**	FM	1	-8.10	-8.60	-29.60	-63.20	-53.33	-53.70	-53.20	-63.20	-63.20	-63.20	-60.31	-60.69	-60.19
3	4	FM	1	FM	1	FM	1	**FM**	**5**	-7.50	-8.80	-30.16	-63.96	-52.66	-52.66	-52.66	-63.96	-63.96	-63.96	-59.65	-59.65	-59.65
0	4	**FM**	**1**	FSK	1	FSK	1	FSK	1	-9.80	-8.17	-29.45	-62.62	-62.38	-62.75	-62.25	-62.62	-62.62	-62.62	-62.38	-62.75	-62.25
1	4	FSK	1	**FM**	**1**	FSK	1	FSK	1	-8.50	-8.60	-29.75	-63.35	-61.13	-61.75	-60.25	-63.35	-63.35	-63.35	-61.13	-61.75	-60.25
2	4	FSK	1	FSK	1	**FM**	**1**	FSK	1	-8.10	-8.70	-29.60	-63.30	-59.95	-60.20	-59.70	-63.30	-63.30	-63.30	-59.95	-60.20	-59.70
3	4	FSK	1	FSK	1	FSK	1	**FM**	**1**	-7.50	-8.83	-30.16	-63.99	-59.29	-59.66	-59.16	-63.99	-63.99	-63.99	-59.29	-59.66	-59.16
0	4	**FM**	**5**	FSK	1	FSK	1	FSK	1	-9.80	-8.17	-29.45	-62.62	-55.13	-55.25	-54.75	-62.62	-62.62	-62.62	-62.11	-62.24	-61.74
1	4	FSK	1	**FM**	**5**	FSK	1	FSK	1	-8.50	-8.60	-29.75	-63.35	-54.75	-54.75	-54.75	-63.35	-63.35	-63.35	-61.74	-61.74	-61.74
2	4	FSK	1	FSK	1	**FM**	**5**	FSK	1	-8.10	-8.70	-29.60	-63.30	-53.58	-53.70	-53.20	-63.30	-63.30	-63.30	-60.56	-60.69	-60.19
3	4	FSK	1	FSK	1	FSK	1	**FM**	**5**	-7.50	-8.83	-30.16	-63.99	-52.66	-52.66	-52.66	-63.99	-63.99	-63.99	-59.65	-59.65	-59.65

Table 9. FM channel change

Channel Change																							
Test Chan.	**Rep.**	**CH0**		**CH1**		**CH2**		**CH3**		**Link Loss [dB]**			**Fixed Channel Interference Power [dBm]**	**Signal Channel Power[dBm]**			**Individual Interference Power [dBm]**			**Individual Signal Power [dBm]**		
		Signal	**No.of Signals**	**Signal**	**No.of Signals**	**Signal**	**No.of Signals**	**Signal**	**No.of Signals**	**Signal**	**Interf.**	**Atten.**		**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**
0	4	**ARD**	**2**	FSK	1	FSK	1	FSK	1	-10.30	-8.17	-29.45	-62.62	-51.38	-54.25	-49.25	-62.62	-62.62	-62.62	-54.39	-57.26	-52.26
1	4	FSK	1	**ARD**	**2**	FSK	1	FSK	1	-11.50	-8.60	-29.75	-63.35	-53.75	-55.25	-52.75	-63.35	-63.35	-63.35	-56.76	-58.26	-55.76
2	4	FSK	1	FSK	1	**ARD**	**2**	FSK	1	-11.20	-8.70	-29.60	-63.30	-52.80	-53.30	-51.80	-63.30	-63.30	-63.30	-55.81	-56.31	-54.81
3	4	FSK	1	FSK	1	FSK	1	**ARD**	**2**	-12.20	-8.83	-30.16	-63.99	-47.86	-48.86	-47.36	-63.99	-63.99	-63.99	-50.87	-51.87	-50.37
0	3	**RAD**	**1**	FSK	10	FSK	5	FSK	5	-9.60	-8.17	-29.45	-28.62	-55.15	-55.55	-54.05	-38.62	-38.62	-38.62	-55.15	-55.55	-54.05
1	3	FSK	10	**RAD**	**1**	FSK	5	FSK	5	-8.30	-8.60	-29.75	-29.35	-52.93	-55.05	-51.05	-29.35	-29.35	-29.35	-52.93	-55.05	-51.05
2	3	FSK	10	FSK	5	**RAD**	**1**	FSK	5	-8.00	-8.70	-29.60	-29.30	-51.25	-53.60	-50.10	-36.29	-36.29	-36.29	-51.25	-53.60	-50.10
3	3	FSK	10	FSK	5	FSK	5	**RAD**	**1**	-7.73	-8.83	-30.16	-29.99	-49.41	-51.89	-46.89	-36.98	-36.98	-36.98	-49.41	-51.89	-46.89
0	3	**RAD**	**2**	FSK	10	FSK	5	FSK	5	-9.60	-8.17	-29.45	-28.62	-49.22	-50.05	-48.55	-38.62	-38.62	-38.62	-52.23	-53.06	-51.56
1	3	FSK	10	**RAD**	**2**	FSK	5	FSK	5	-8.30	-8.60	-29.75	-29.35	-60.88	-61.05	-60.55	-32.36	-32.36	-32.36	-63.89	-64.06	-63.56
2	3	FSK	10	FSK	5	**RAD**	**2**	FSK	5	-8.00	-8.70	-29.60	-29.30	-46.56	-48.60	-45.10	-36.29	-36.29	-36.29	-49.57	-51.61	-48.11
3	3	FSK	10	FSK	5	FSK	5	**RAD**	**2**	-7.73	-8.83	-30.16	-29.99	-59.22	-59.39	-58.89	-36.98	-36.98	-36.98	-62.23	-62.40	-61.90

Table 10. Airborne and ground radar channel change

iii. *Channel Change vs. Graceful Shutdown Threshold Evaluation*

Description

This experiment consisted in measuring the threshold for which the MCU, when being forced to leave its current channel, will determine to either operate on a noisy channel or begin a graceful shutdown procedure. In contrast to the channel change and graceful shutdown tests, for this experiment, the channel power on the "secondary" channels was changed on every repetition. The power of the interference signal on the channel of interest was increased (manually) in order to trigger a channel change or shutdown event .

Channel Change vs Graceful Shutdown Calibration																	
Test Channel	Rep.	CH0		CH1		CH2		CH3		Link Loss			Interference Channel Power (RMS) [dBm]			Fixed Signal Power (RMS) [dBm]	Event Triggered
		Signal	No.of Signals	Signal	No.of Signals	Signal	No.of Signals	Signal	No.of Signals	Signal	Interf.	Atten.	Mean	Min	Max		
0	1	FSK	1	WBD	1	WBD	1	WBD	1	-9.8	-5.7	-32.35	**-88.05**	**-88.05**	**-88.05**	-72.15	Ch. Change
0	1	FSK	1	WBD	1	WBD	1	WBD	1	-9.8	-5.7	-32.35	**-85.05**	**-85.05**	**-85.05**	-71.65	Ch. Change
0	1	FSK	1	WBD	1	WBD	1	WBD	1	-9.8	-5.7	-32.35	**-80.05**	**-80.05**	**-80.05**	-72.15	Ch. Change
0	1	FSK	1	WBD	1	WBD	1	WBD	1	-9.8	-5.7	-32.35	**-77.05**	**-77.05**	**-77.05**	-71.65	Ch. Change
0	1	FSK	1	WBD	1	WBD	1	WBD	1	-9.8	-5.7	-32.35	**-74.05**	**-74.05**	**-74.05**	-72.15	Ch. Change
0	2	FSK	1	WBD	1	WBD	1	WBD	1	-9.8	-5.7	-32.35	**-73.05**	**-73.05**	**-73.05**	-71.65	**SHUTDOWN**
0	1	FSK	1	WBD	1	WBD	1	WBD	1	-9.8	-5.7	-32.35	**-71.05**	**-71.05**	**-71.05**	-72.15	**SHUTDOWN**

Table 11. Channel Change vs Shutdown Threshold

Objective:

This is a calibration test. For different signals on the secondary channels, measure the interference power level that allows the MCU to operate on a given channel when being forced to abandon the current channel.

Observation:

This test should be repeated using a single (narrowband) signal on the alternative channels. The 'Noise in dB' value reported as seen by the MCU registries was close to 20 dB at the threshold value. That is, if noise is below this threshold, then the MCU can operate in the noisy environment. Otherwise, it will shutdown.

iv. System response due to link loss

Description

Perform test (steps 1-7 below) for different interferers

1. Set operating band of MMN system to a given channel
2. Insert variable attenuator between the MCU and Implant devices.
3. Set initial attenuation level to 0 [dBm]. (Note: initial power level to be determined at start of test).
4. Increase attenuation level by .5 [dB] steps until implant starts graceful shutdown procedure. For each dB step report the total downlink and uplink errors, total stimulation loss events (see I.E), average number of 5 [kHz] bins for each channel, average power exponent for each channel, average noise floor for each channel, average of worst RSSI implant.
5. Record attenuation level and time to shutdown state.
6. Repeat test and report minimum, maximum, and mean of attenuation level, time to shutdown.
7. Repeat steps 1 through 6 with operating channel set to remaining channels.

Test Objective

- Characterize the minimum signal level required at the ISD's antenna to maintain operability
- Using different channel models, the concept of a minimum signal level can be translated to a maximum distance between operational ISDs and the MCU.

Observations

- The diagram on Figure 11, shows the circuit used for measuring the Graceful Shutdown event due to link loss. The column labeled "Board Loss" reflects an 8.5 [dB] directional loss in the circuit that is reported by AMF. This loss has not been independently verified.

Device	Attenuation [dB] Nominal	Measured
(Splitter. ZFSC-2-1-W) + (Var. Attenuator: ZX76-31R5)	5.1	6.3
Var. Attenuators:JFW 50DR-001	9	9
Splitter: ZFRSC-2050	7	7.3
Var. Attenuators:JFW 50DR-001	13	13
Splitter: ZFSC-2-1-W	3.5	3.7
Splitter: ZFSC-8-4-W	11	10.2
TOTAL: MCU to ISDs	**48.6**	**49.5**

Table 12. Link Loss between MCU and ISDs

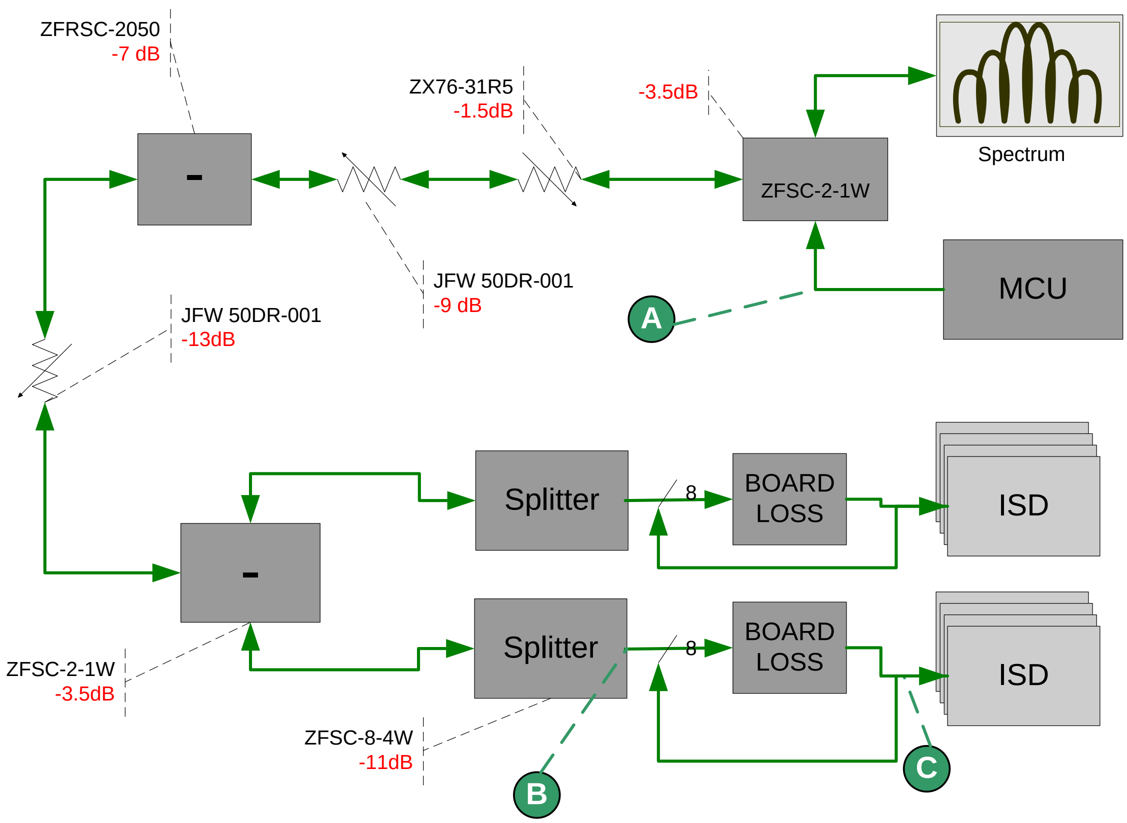

Figure 11. Link Loss due to Attenuation

Channel	Rep.	ZX76-31R5 Variable Attenuator [dB] Mean	Min	Max	Board Loss [dB]	Component Loss [dB]	**Mean Power Loss [dB]** A -> B	A -> C
0	10	-24.2	-24.5	-24	-8.5	-49.5	-73.7	-82.2
1	5	-24.7	-25	-24	-8.5	-49.5	-74.2	-82.7
2	5	-26.2	-26.5	-26	-8.5	-49.5	-75.7	-84.2
3	5	-26.2	-26.5	-26	-8.5	-49.5	-75.7	-84.2

Table 13. Link loss

Test Summary

Power measurements indicate that the MCU and ISDs can communicate as long as the link losses are below 82 [dB]. Using this value as an input to a channel model of choice (i.e. Okumara-Hata, free space, etc) can provide an estimate of the tolerable distance between the MCU and ISD's antennas.

4. Conclusions

The test results that appear in Section 3.3 indicate that the AMF MMN System performs according to its specifications (for the wired testing conditions described in Section 1.3) and is able to:

- Operate in presence of incumbent users under the considerations of Section 1.3.
  - MMN can spectrally excise narrowband incumbent users
  - MMN is able to change channels without suspending critical functions
  - MMN is able to gracefully shutdown in a communication link service-loss scenario
- MCU is able to sense the signal level of incumbent users in order to avoid MMN system interfering with them by successfully changing channels.

5. References

1. United States Department of Commerce. National Telecommunications and Information Administration (NTIA). "Petition for rulemaking to establish a new Medical Micropower Network Service in the band 413-457 [MHz]". March 25, 2009.
2. Telecommunications Industry Association (TIA). Training Guide TG-001 for P25 Radio Systems. Online: http://www.p25.com/resources/P25TrainingGuide.pdf.
3. F. Xiong. "Digital Modulation Techniques". 2nd Ed. Artech House. 2006

Appendix A: Signal Description

- **Frequency Shift Keyed (FSK) Signals**

The base band (BB) single side band (SSB) FSK signals were generated in software using Matlab. A set of random (uniformly-distributed) numbers was used as the data stream. Based on the specifications [1], the data rate was selected to be 4800 [Symbols/sec] with a frequency deviation of 600Hz. Before the signal was sent to the AWG, a Blackman window **Error! Reference source not found.** was used for cross-fading, with a duration of 200 [µsec]. To ensure that no high frequency noise was artificially injected into the spectrum, a 40 [MHz] anti-aliasing filter was applied in the signal generator, as shown in Figure 12. To simulate a worst-case scenario the signals were uniformly spaced within the band of interest.

The time and frequency spectrum corresponding to three single FSK signals at the center of channels 0, 1 and 2 is shown in Figure 13. The center frequency for these waveforms is {-39.8 -27.5 -14.91} [MHz]. When these signals are mixed at the AWG with a carrier at 456.31 [MHz], the resulting waveforms translate to channels centered at {416.51 428.81 441.40} [MHz]. This corresponds to the center of channels 0, 1 and 2, as shown in Figure 6. Figure 14 shows a similar interference scenario case, where 10 FSK signals appear on channel 0, and 5 FSK signals are uniformly spaced in channels 1 and 3.

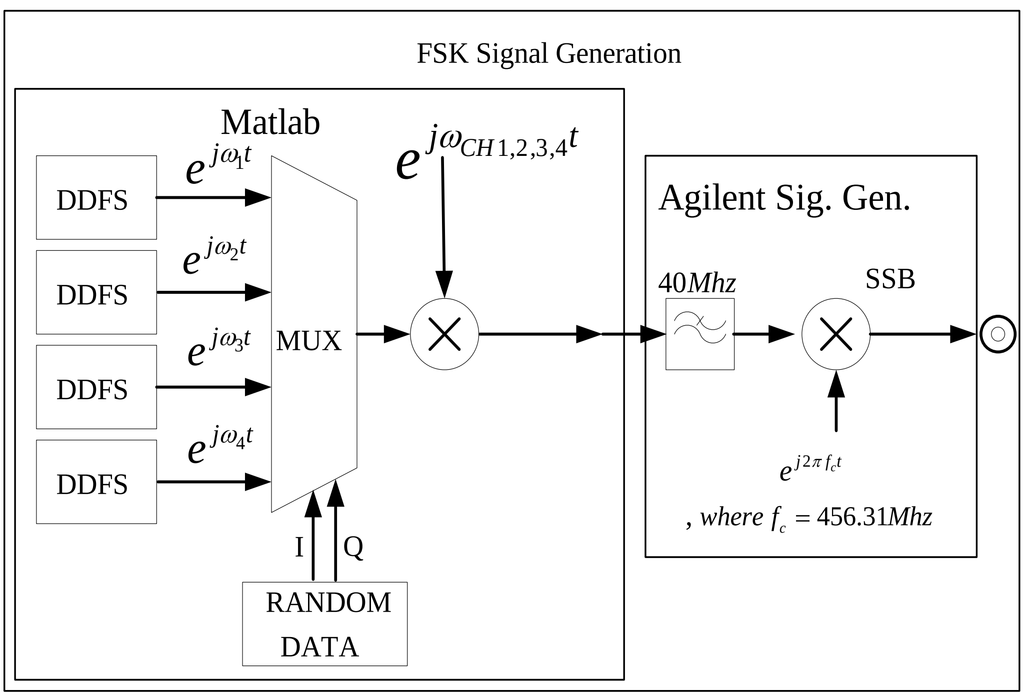

Figure 12. FSK Signal Generation

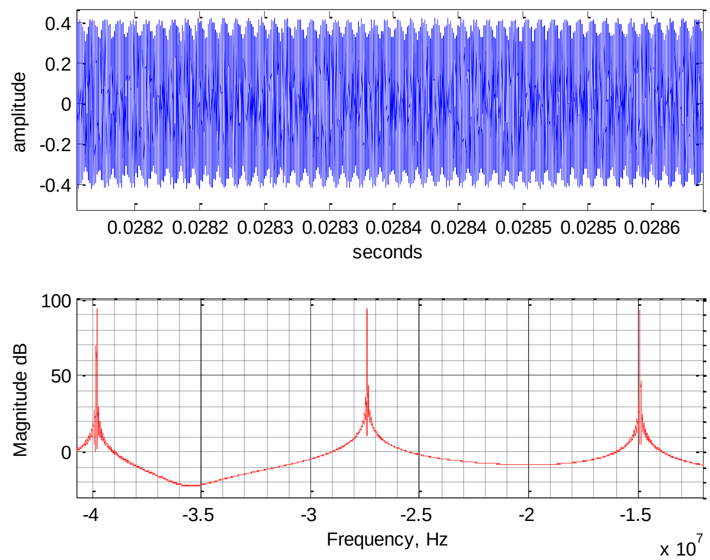

Figure 13. FSK: Time and Frequency Spectrum

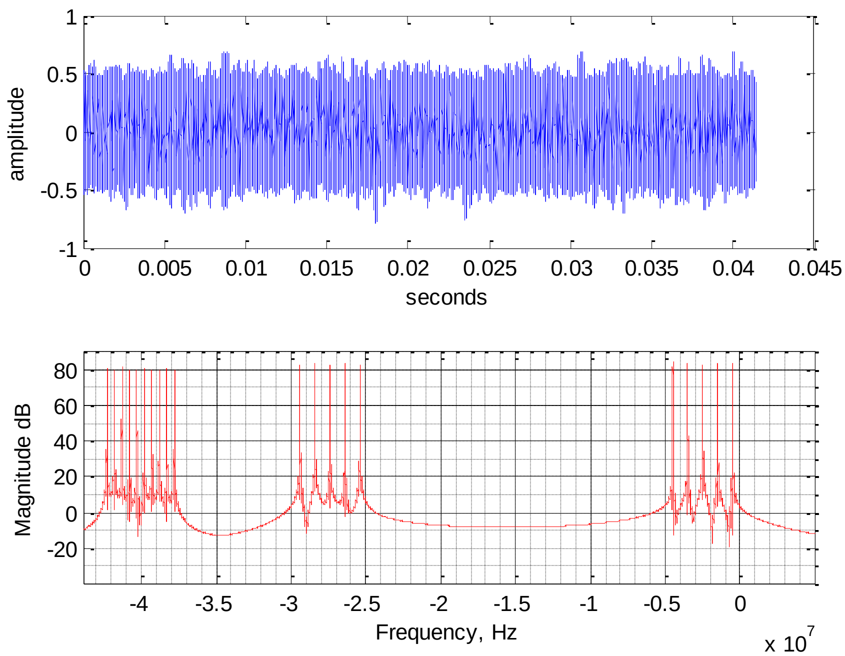

Figure 14. FSK interference signals

- **Frequency Modulated Signal**

The information stream for the FM signal was generated using a chirp function that sweeps frequencies in the range of 0-3 [kHz]. A detailed description of the signals used can be found in Section 3.2.

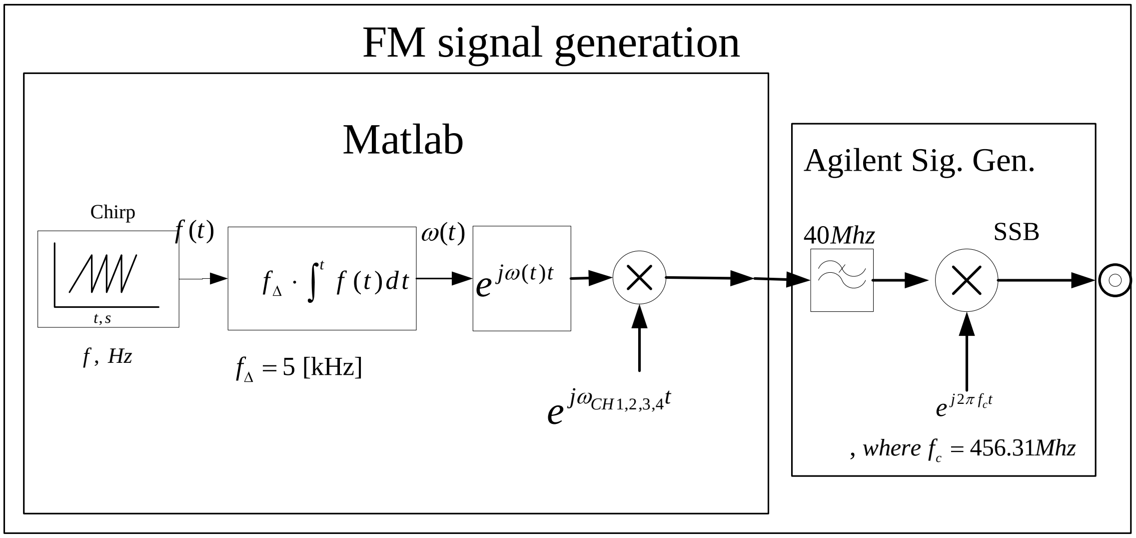

Figure 15. FM Signal Generation

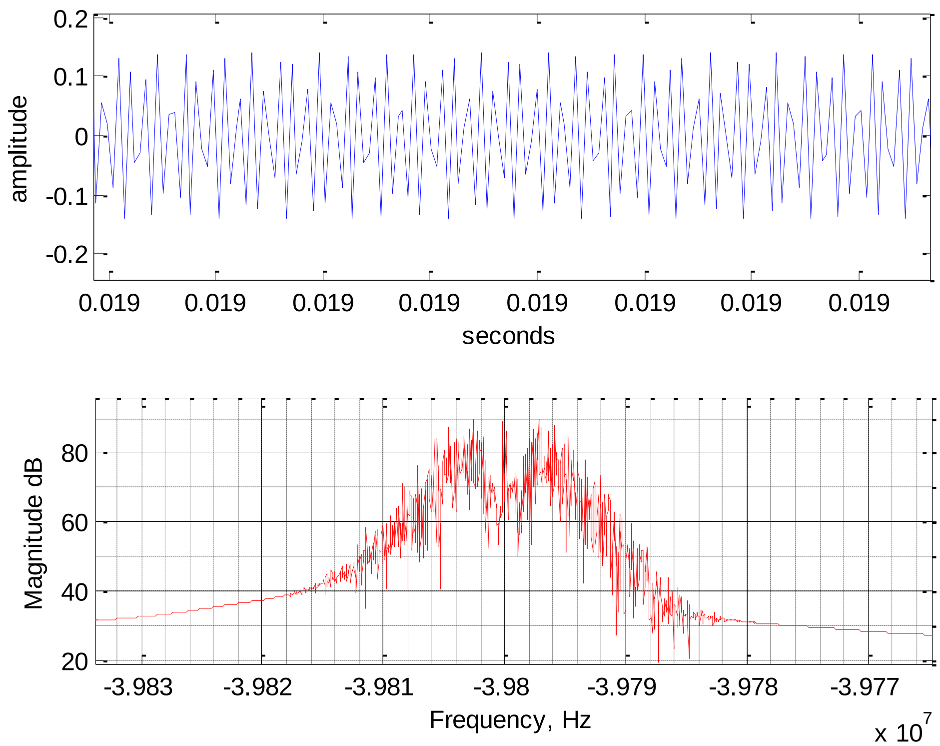

Figure 16. FM: Time and Frequency Spectrum

The time and frequency spectrum corresponding to a single FM signal at the center of channel 0 is shown in Figure 16. The center frequency for this waveform is -39.8 [MHz]. When this signal is mixed at the signal generator with a carrier at 456.31 [MHz], the resulting waveform translates to 456.31-39.8 = 416.51 [MHz], which corresponds to the center of channel 0.

- **Ground RADAR**

Ground radar signals were generated according to signal specifications in [1], with a 41 [Hz] repetition rate. The generation schematic for this signal type is illustrated in Figure 17. Figure 18 illustrates a case where two ground radar signals coexist on the same channel.

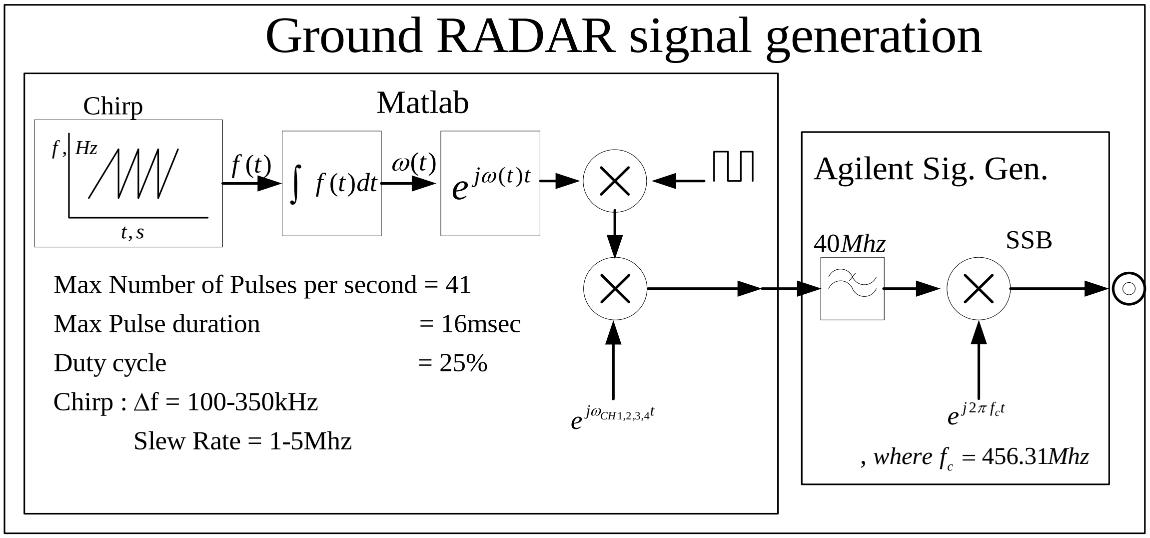

Figure 17. Ground RADAR Signal Generation

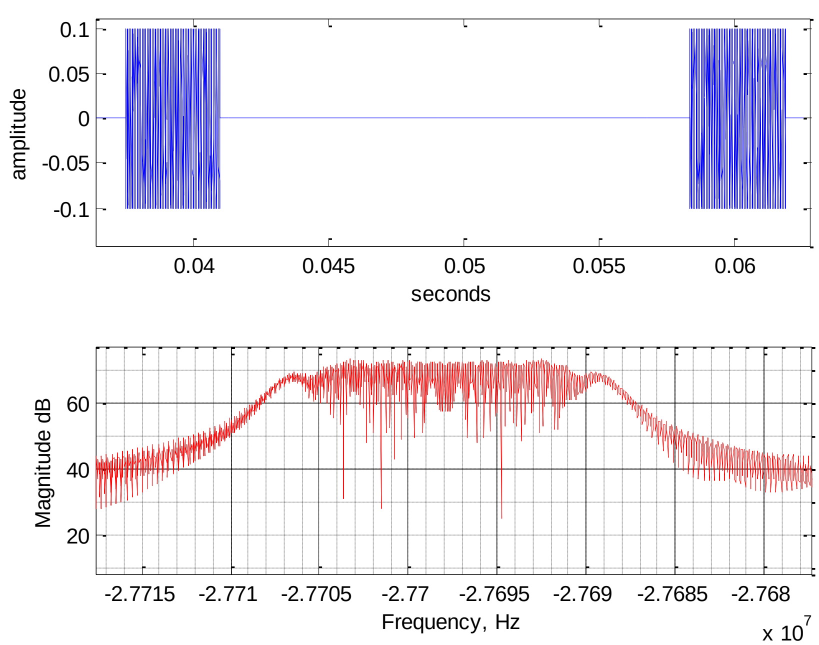

Figure 18. Ground Radar. Time and Frequency Spectrum

- ## Airborne RADAR

Airborne radar signals were generated according to signal specifications in [1]. These signals are similar to the ground radar case, but with a shorter pulse duration, between 1 and 8 [μ sec]. The generation schematic for this signal type is illustrated in Figure 19.

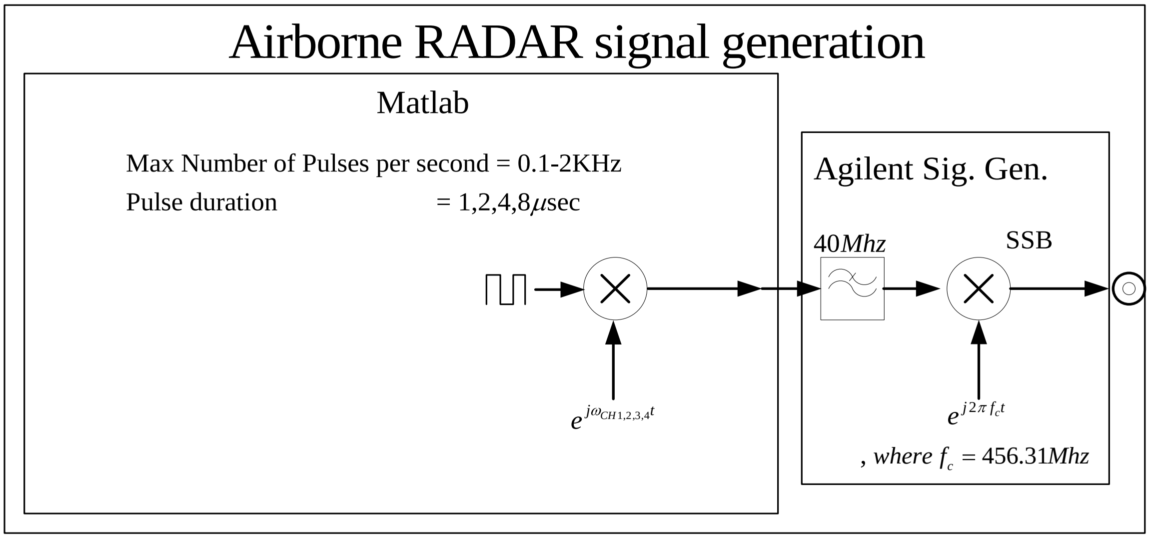

Figure 19. Airborne RADAR Signal Generation

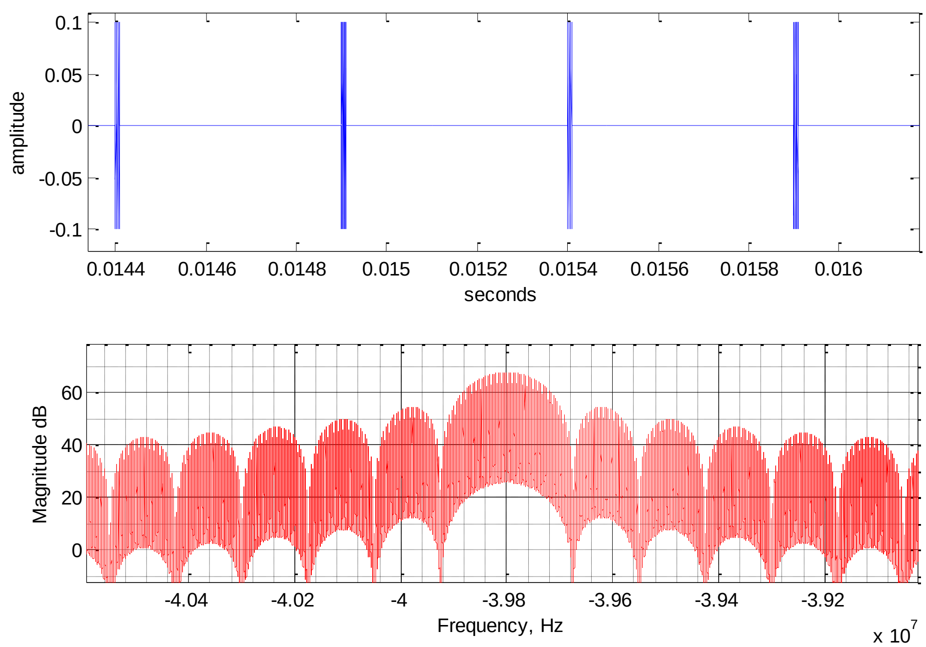

Figure 20. Air Radar: Time and Frequency Spectrum

The time and frequency spectrum corresponding to a single airborne radar signal at the center of channel 0 is shown in Figure 20. The center frequency for this waveform is -39.8 [MHz]. When this signal is modulated at the signal generator with a carrier at 456.31 MHz, the resulting waveform translates to 456.31-39.8 = 416.51 [MHz], which corresponds to the center of channel 0.

- ## Generic Wide Band Signal

A generic wideband signal (see Figure 21) was used to simulate interference from wideband analog television signals. To create this signal , random data was filtered using a square root-raised cosine (256-tap) filter, generating a 5 [MHz] wideband signal shown in Figure 22

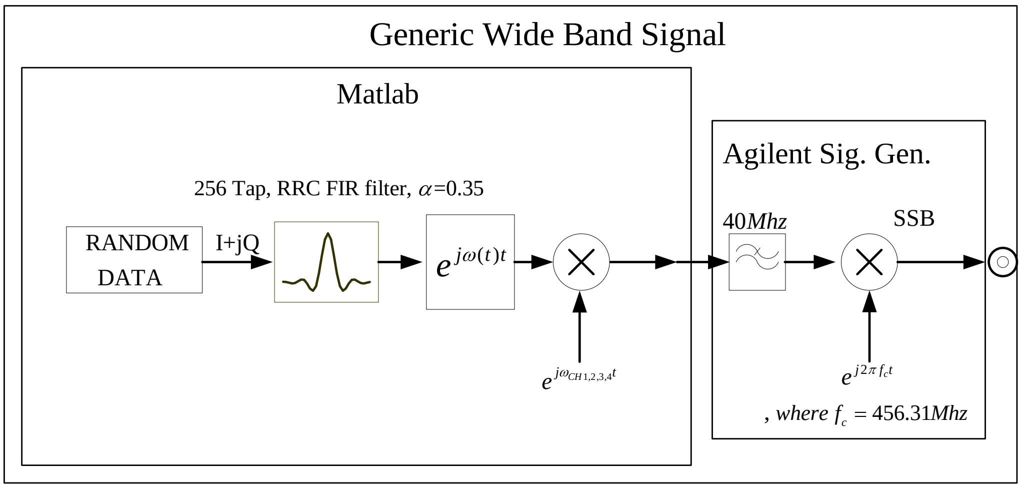

Figure 21. Generic Wide Band Signal Generation

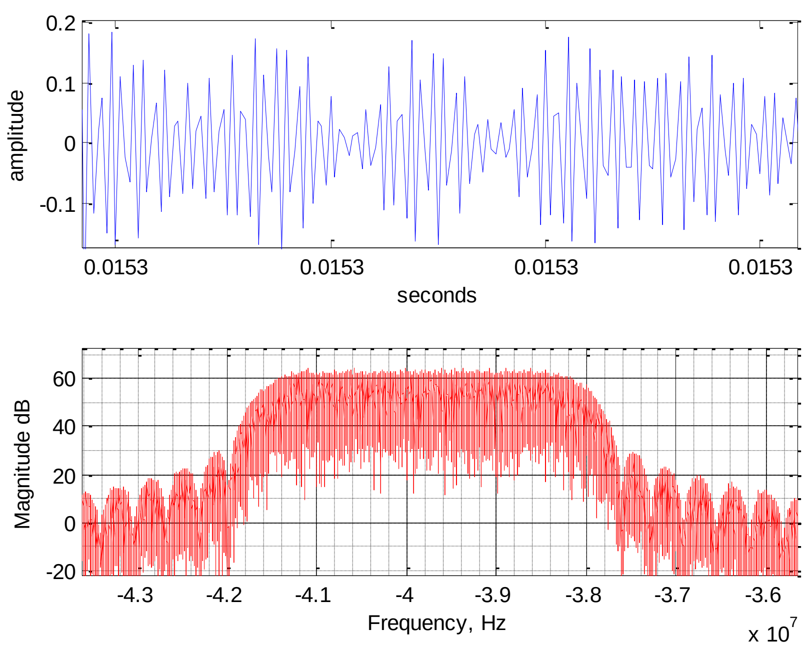

Figure 22. Generic Wideband Signal: Time and Frequency Spectrum

- **Enhanced Position Location Reporting System (EPLRS)**

EPLRS is a synchronous Time Division Multiple Access (TDMA) system that provides the basic tactical functions of identification, position location, and navigation information automatically to a centralized control station. All the cases tested on this report, used a worst-case scenario where all 8 signals were present simultaneously in the band.

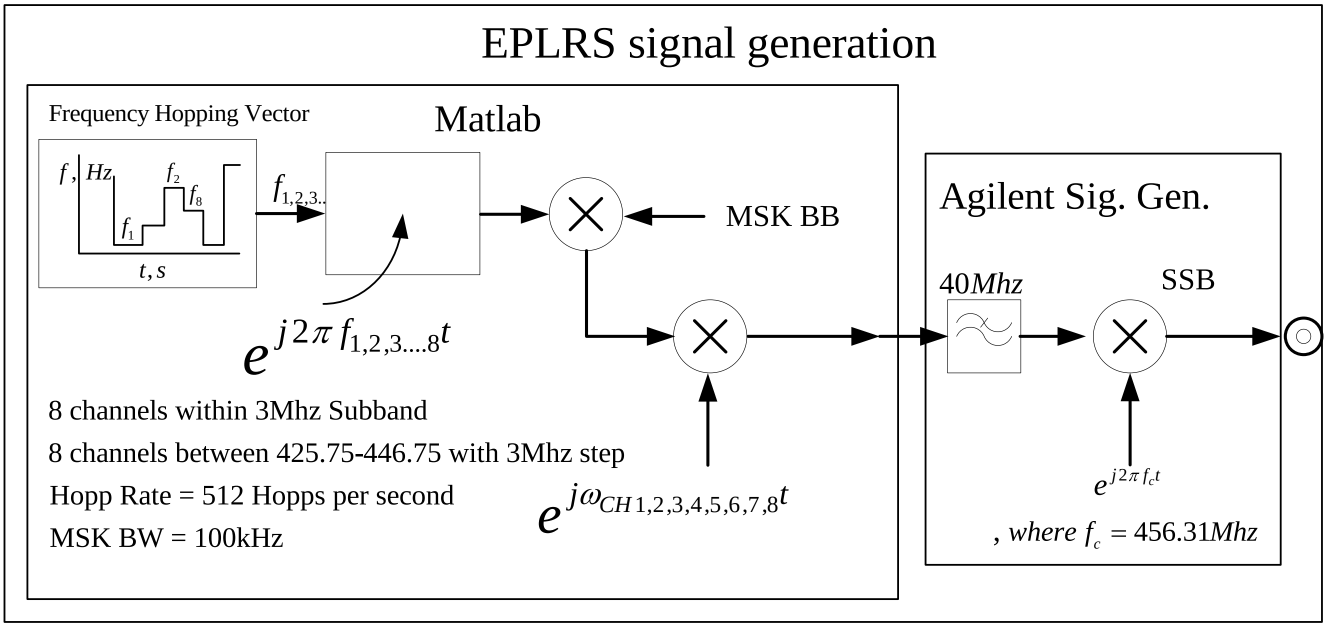

Figure 23. EPLRS Signal Generation

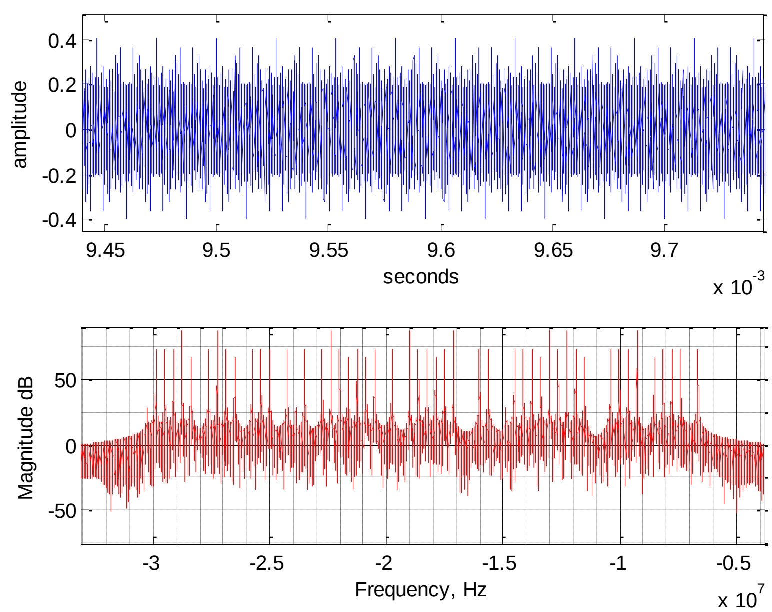

Figure 24. EPLRS Time and Frequency Spectrum

REV	NOTES	DAR NUMBER	DATE
01	Initial Release	3272	10/19/09 RJG

Company Confidential

Engineering Test Report

Uplink Path Loss of Four-Wire Antenna Connection in Simulated FEBPM Implant

ALFRED MANN FOUNDATION

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Author/Revised by: Howard Stover	Reviewed by: Eusebiu Matei	Approved by: David Melbye
Signature: Date:	Signature: Date:	Signature: Date:

1. PURPOSE

These investigations were conducted to determine the expected received signal strength and path loss while transmitting from a simulated implant through tissue phantom at various depths of implant for a range of angles and distances around a body tissue model.

2. SCOPE

2.1. This experiment employs a simulated implant device approximately 25 mm long by 3.5 mm in diameter connected to a signal generator operating at 416 MHz.

2.2. The results reported are for the implant configuration using the 4-wire antenna connection, without isolating inductors. Other configurations were examined; this configuration is most similar to the final design

2.3. Tests were conducted in an open area and do not account for propagation within buildings or reflections from standing objects.

3. SUMMARY

The experiments were conducted using tissue phantom in a cylindrical polyethylene container that was roughly body-sized. The experiments suggested that the radiation pattern from a simulated implant with an antenna approximately 25 mm long at 400 MHz follow the 40 dB/decade roll off predicted by the dual slope propagation model beyond the calculated breakpoint distance when the transmitting and receiving antennas are close to the ground. The minimum loss for a shallow implant depth was found to be approximately 20 dB when compared to the signal level predicted for a hemispheric radiator by the dual slope model at 10 m distance. The loss relative to the dual slope model increases at smaller distances. Additionally, the increased loss due to implant depth was observed to be approximately 1.25 dB per cm of depth along the path of maximum signal. The signal strength was greater than would be predicted by this relation on the weak-signal side of the body simulator due to effects of the shape and size of the body simulator compared to the wavelength of 0.71 m. in air.

4. REFERENCED DOCUMENTS

Tissue Recipe and Calibration Requirements, Spectrum Sciences Institute, SSI-DRB-TP-D01-033

Simulated Biological Materials for Electromagnetic Radiation Absorption Studies, G. Hartgrove et al, Bioelectromagnetics 8:29-37, 1987

5. DEFINITIONS

Tissue Phantom	A gel designed to electrically simulate body tissue
Balun	A device to interconnect balanced to un-balanced RF loads
Breakpoint	The distance at which the pathloss changes from the free-space model
Coax	Coaxial cable RF transmission line
dB	Decibel –a unit of relative signal level on a log scale

m	meter(s)
Pathloss	The signal loss in dB over a particular transmission path
RF	Radio frequency

6. EQUIPMENT AND MATERIALS

6.1. HP 8660C RF Signal Generator, SN 2142A04045, Cal 08/15/07

6.2. IFR A-7550 Battery-operated Spectrum Analyzer, SN 34580-311, Cal 08/17/07

6.3. Half-wave dipole test antenna, hand made, with transmission line balun and 75 Ohm cable, connected through 1.5:1 balun

6.4. Simulated Implant, hand made, with transmission line balun

6.5. Tissue Phantom, see Spectrum Sciences Institute, SSI-DRB-TP-D01-033

6.6. Body simulator: 5 gallon polyethylene bucket, 30 cm diameter

6.7. Power generator, Honda

7. RESULTS

7.1. The simulated implant was connected to a miniature coax transmission line with a transmission line balun constructed of brass tubing and Teflon® rod, tuned for the test frequency of 400 MHz. The line loss was measured at 1.95 dB. The signal generator was set to output 1.95 dBm so that the net power delivered to the implant was approximately 0 dBm.

7.2. The simulated implant was constructed using the major internal implant components to provide a realistic model. The connections to the balun were made as short as possible to prevent spurious radiation. The connections to the internal components were made through a hole that was laser blasted into the center of the case. The connections were sealed with wax to prevent tissue phantom material from entering the device when immersed in the phantom container. The connected device was tested for directionality to determine whether or not the transmission line was effectively decoupled from the simulated implant. The null was observed to be 25 -30 dB comparing off-axis to on-axis, suggesting the decoupling was quite good.

7.3. The simulated implant and attached balun can be seen in Figure 1.

Figure 1: Simulated Implant and Attached Balun

7.4. Figure 2 depicts a close-up of the simulated implant showing the wax moisture protection

Figure 2: Simulated Implant with Wax Moisture Protection

7.5. All tests were conducted with the signals emitted from the simulated implant placed at various distances from the sidewall of the tissue phantom container. Signals were received using the test dipole antenna at various distances from the container.

7.6. As seen in Figure 3, the receiving antenna was a carefully tuned dipole with a similar transmission line balun connected using 75 Ohm miniature coax cable. The feed line was connected to the spectrum analyzer through a 1.5:1 commercial balun transformer to provide a 50 Ohm match.

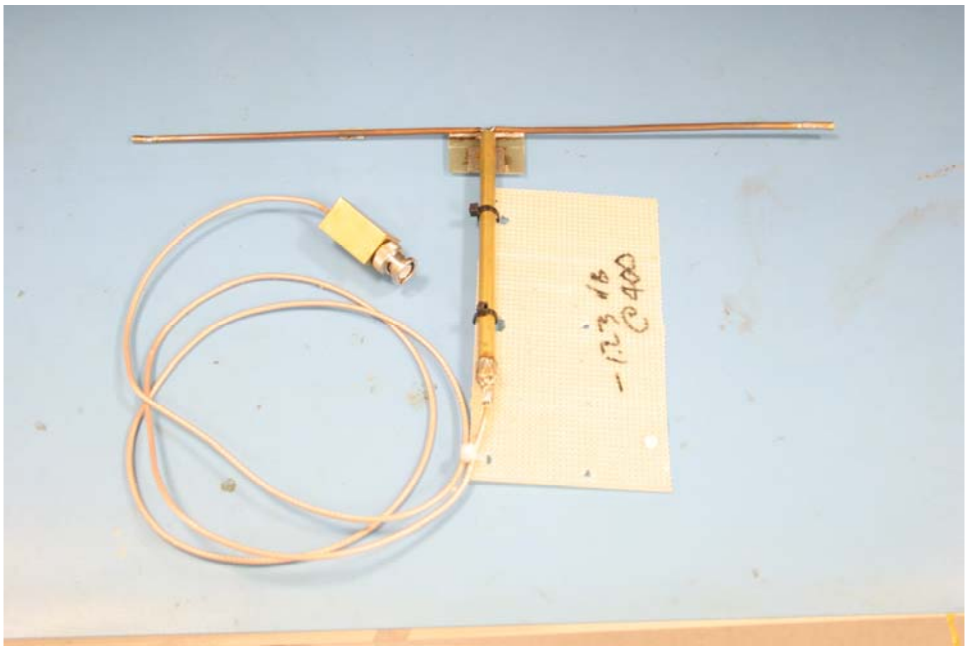


Figure 3: Receiving Antenna

7.7. The human body simulator was a 5 gallon polyethylene bucket filled approximately ¾ full with the tissue phantom mixture.

NOTE: The shape of the body simulator affects the propagation results. A large rectangular tank, for example, gives rather different results from a more cylindrical shape. Using a rounded shape closer to body size results in a greater radio wave field than would be estimated using a large, rectangular tank or wall of tissue phantom. These observations correlate with simulations.

7.8. Tests were conducted in an open site approximately five acres in area with no buildings, pavement, or underground structures. Metal signs and fences were a minimum of 100 feet away from the test area.

7.9. Test signals were generated using a standard laboratory signal generator powered by a small AC generator. The signal was unmodulated. The spectrum analyzer was battery operated to avoid unwanted signal pick up and was placed on the lower shelf of a fiberglass cart to which was mounted the test antenna. Both antennas were approximately 1.1 m above the ground and horizontally polarized.

7.10. The simulated implant was placed at a particular distance from the sidewall of the polyethylene bucket to simulate implant tissue depth. The angular direction of maximum signal strength was established by placing the sidewall of the bucket directly in line with the transmission path and checking that the orientation of the implant antenna was perpendicular to the transmission path. The cart containing the receiving antenna and the spectrum analyzer was then moved back and forth in a straight line along the transmission path until the desired received level was observed on the spectrum analyzer display. The body simulator bucket was then rotated in increments of approximately 45 degrees using a turntable and the distance to the receiving antenna was adjusted along the transmission path until the desired level was again observed.

7.11. The above steps were repeated for the different received signal strength levels in increments of 10 dB to establish a family of signal strength contours. Once a contour was completed, the simulated depth of implant was changed and the process repeated to generate a new set of contours.

7.12. Contours were created for depths of approximately 2 cm, 4 cm, 8 cm and 15 cm, which is the center of the bucket. Signal strength levels were established at -60 dBm, -70 dBm, -80 dBm, and -90 dBm.

7.13. The results of the tests for the direction of maximum signal strength were collected and are reported in Figures 4 and 5 below. Calculated signal strengths for free-space propagation and the smoothed dual-slope propagation cases are also plotted for reference.

7.14. The dual slope "break point" or transition distance for antenna heights of 1.1 m is approximately 6.8 m. This break can be observed in the data, despite the lack of resolution in the data set. The smoothed dual-slope curve is defined by the expression:

$L = L_1 + 10n_1\log_{10}(r) + 10\,(n_1 - n_2)\log_{10}(1 + r/rb)$

L = pathloss, dB, at distance r

L_1 = reference level at 1 m (measured or computed using free-space model)

rb = breakpoint distance, m = $4/\lambda(h_1\ h2)$

n_1 = short-distance loss constant, dB/decade

n_2 = long-distance loss constant

The free-space pathloss is plotted at 20 dB/decade for a wavelength of 0.71m.:

$L = (4\,\pi\,r/\lambda)^2$

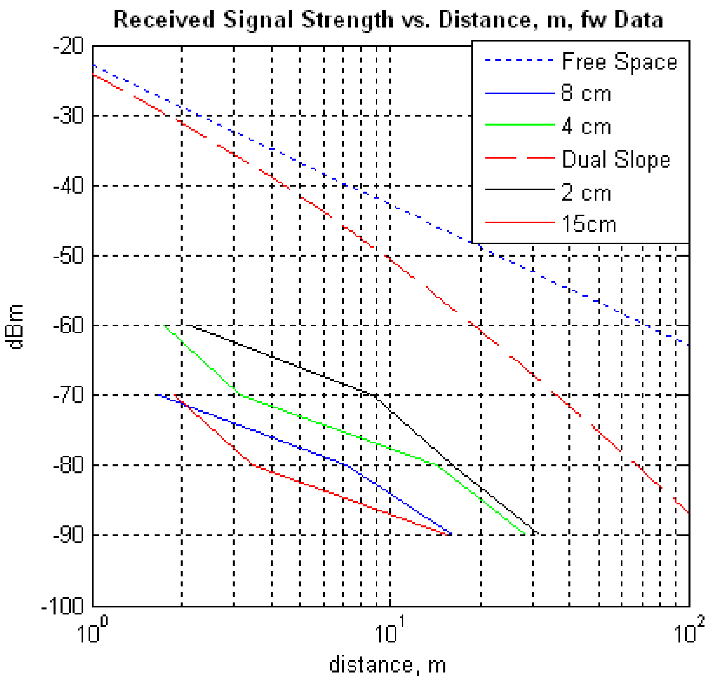


Figure 4: Received Signal Strength, Four-Wire

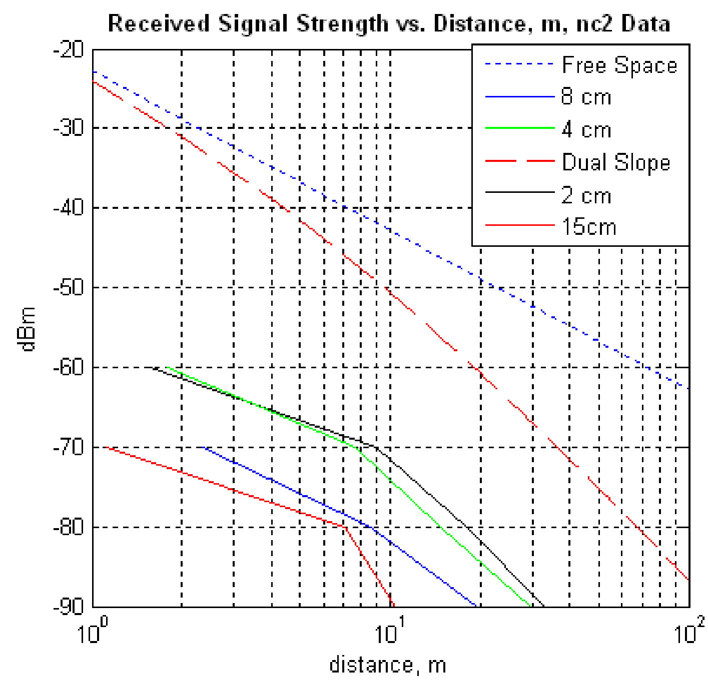


Figure 5: Received Signal Strength, New Case 2

7.15. Two different data collections for slightly different implant case configurations were made. Though not identical largely due to the common variability of such measurements, good general agreement is evident, but the data do not provide a sufficiently consistent basis for reliable statistical analysis. Both data sets suggest that the implant signal at 10 m is approximately 22 dB lower than would be predicted by the dual slope estimator for a shallow (2 cm) implant depth. As the distance increases, the signal level remains at approximately this difference from the dual slope level. The difference increases to between 25 dB and 30 dB at 2 m. The slope of the pathloss curve appears shallower than 20 dB/decade, the free-space rate and the asymptote of the dual-slope estimate. This effect is likely due to the influence of the shape of the body simulator that contains the tissue phantom medium.

7.16. The loss curve slope beyond the breakpoint is roughly 40 dB/decade as predicted by the dual slope model.

7.17. The second component of received signal strength is the loss due to implant depth in the tissue phantom. This relationship is more difficult to extract from the data due to the relatively few sample points and high variability. In the figure below, interpolated data for 10 m distance from the implant antenna are plotted for both data sets along with the average of the data for the two sets and a least squares fit of the average.

7.18. The relationship of the fit data suggests a slope of approximately 1.25 dB/ cm of tissue depth when places in a round container. The intercept of the fit is approximately -71 dBm. In rough terms at 10 meters range, the signal strength is approximately 20 dB worse than a dipole antenna plus up to approximately an additional 20 dB loss depending on the implant depth. These results, depicted in Figure 6, do not account for orientation differences.

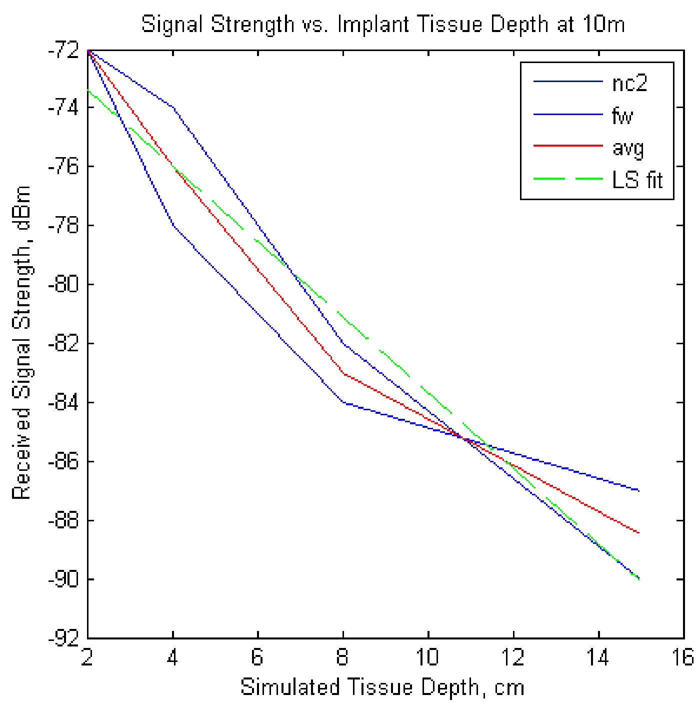


Figure 6: Signal Strength vs. Implant Tissue Depth at 10m

7.19. At approximately 4 m distance from the body simulator the same analysis suggests an intercept point of approximately -64 dBm and a slightly smaller slope of -1.13 dB/cm, as shown in Figure 7.

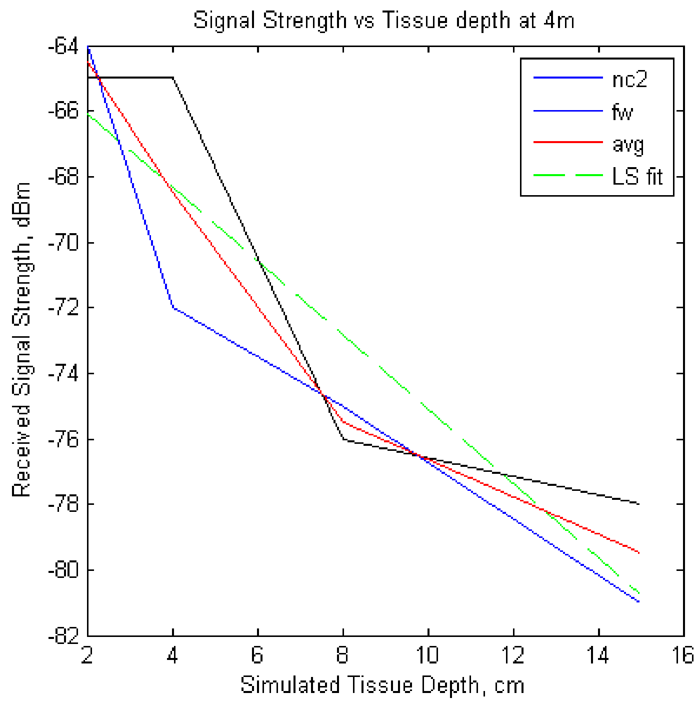


Figure 7: Signal Strength vs. Implant Tissue Depth at 4 m

7.20. A third aspect of propagation from the implant was investigated by examining the signal strength from the opposite side body simulator while the implant depth was small. Under these conditions, the path through the tissue would appear to be quite large, but the observed signal strength is not reduced in proportion to the apparent depth. From the preceding analysis, one might expect the level on the back side of a 2cm deep implant to be reduced by as much as 35 dB compared to the front side. Such a difference would suggest a distance for the same signal level of approximately 0.13 at 40 dB/decade pathloss as observed at distances beyond the breakpoint. The chart in Figure 8 suggests that the ratio is approximately 0.57 for such distances. This difference is attributable to the effects of the shape of the body compared with the wavelength of 0.71 m.

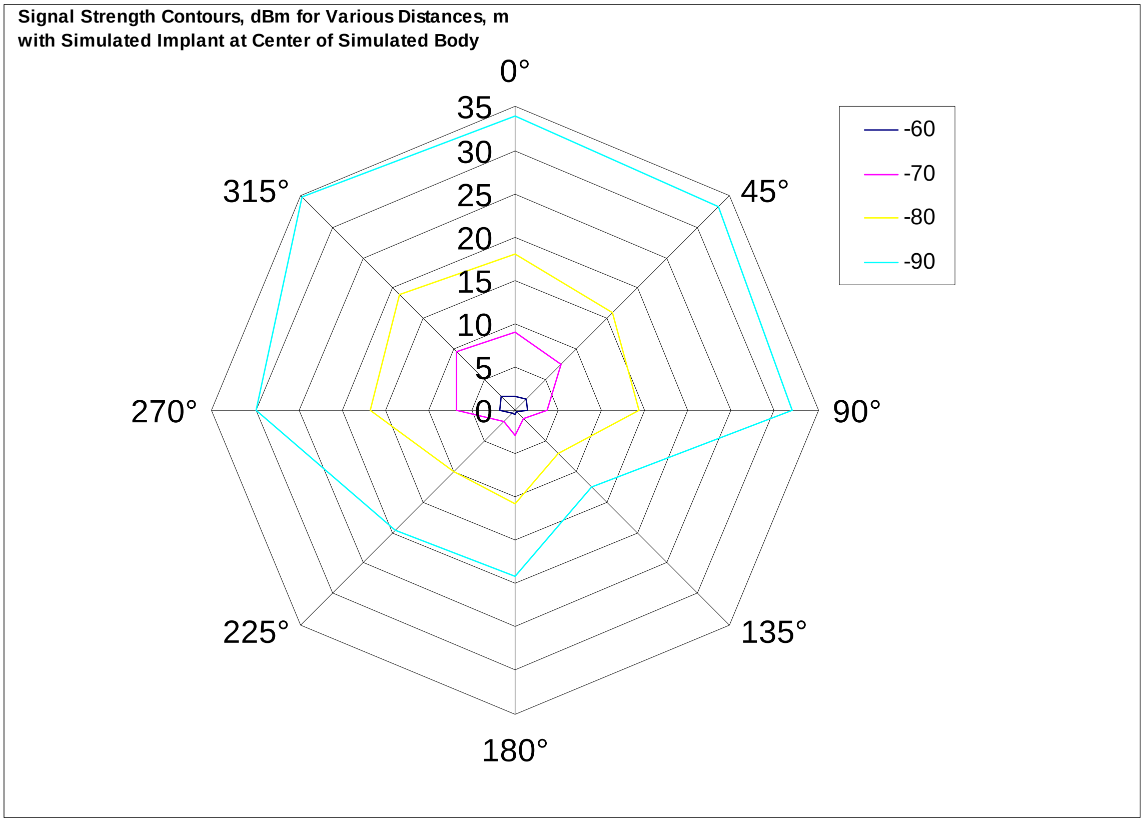


Figure 8: Signal Strength Contours

8. DISCUSSION AND CONCLUSIONS

8.1. It is quite evident from the data that the signal strength for distances exceeding the breakpoint falls off as predicted by dual slope analysis (or two-ray modeling), approximately 40 dB/decade. The rate of loss at distances closer than the breakpoint distance does not appear to strictly follow the 20dB/decade rate predicted by the model. The data suggest that the rate is less that 20 dB/decade of distance. This effect is most likely due to the propagation characteristics of the tissue phantom within a container that is approximately one-half wavelength in diameter.

8.1.1. The combined effects of tissue loss at minimum depth and antenna efficiency result in signal levels that are approximately 20 dB below those predicted for hemispheric radiators using the dual-slope pathloss model.

8.1.2. Increasing the depth of implants causes an increase in the pathloss of approximately 1.25 dB per centimeter of depth along the path of maximum signal strength.

8.1.3. The expected received power observed on the “back” side of the body simulator, where the apparent implant depth might be as much as 28 cm., is stronger than would be predicted by that simulated tissue depth by nearly 25 dB. Experiments conducted at 915 MHz suggest that the shorter wavelength exhibits this stronger signal effect to a far lesser degree as do experiments conducted with relatively larger rectangular tanks. The combination of the body size, shape and the wavelength result in greater signal strength in the weaker signal areas than intuition might suggest.

ALFRED MANN FOUNDATION

January 28, 2011
Howard Stover

We have gathered the information requested subsequent to review of the Aerospace test report. Below is a summary of the six items and our response to each. We are attaching all the documents for convenience

Items requested by JSC/Comsearch:

1) MCU test report verifying basic operating parameters.
    a. Complete receiver sensitivity is not in the supplied hardware test report. From BER curves in un-released DVT report supplied to JSC on 01/26/11, the sensitivity is -90.5 dBm input power for 8 dB S/N
    b. AMF supplied to Comsearch/JSC the MCU hardware test plan and test report
2) Description of the "Graceful Shutdown" process used to protect MMN system users from un-planned communication link outages.
    a. Memo describing the process forwarded on 1/20/11.
3) Explanation of the test rationale used by Aerospace to determine the effectiveness of the MMN spectral excision processing.
    a. Addendum to the Aerospace from Esteban Valles is attached to this memo. This description will be included in the final release of the Aerospace test report.
4) Verification of RADAR test signal parameters used in Aerospace tests.
    a. Test plan was not devised by AMF. The goal was to identify a subset of possible signal types that would pose the greatest difficulty to the AMF detection and channel management algorithms. AMF understands that Comsearch will review the operative signal types and determine if the signal set is a reasonable choice.
5) Verify the MCU receiver BER performance while excising interferers
    a. Implant BER curve was supplied in earlier documents; excision does not apply to the implant receivers
    b. MCU BER curve with and without excision was provided 1/26/11
    c. This chart covers the signal range over which BER performance is degrading, AMF did not conduct tests for the full range of S/I values due to the commitment of time compared to the value of establishing precise values for the higher S/N levels.
    d. AMF believes the S/I information contained in the multipath/fading tests combined with the BER charts addresses the concerns raised by JSC/Comsearch

6) Performance of the detection/excision processes in the presence of interferers that are fading
   a. AMF is attaching a report with this memo of tests conducted with simulated Raleigh fading channels occupied by single and multiple interferers of various signal levels using two MMN path loss models 1) the scenario used in the JSC analysis and the Aerospace tests 2) path models simulating a deep implant with weaker signal levels
   b. The tested signals were a severe case where all the interferers were of equivalent nominal strength and all were processed through an HP 11759C fading simulator using a GSM urban profile with 38 km/hr equivalent Doppler.
   c. AMF has performed extensive testing with captured signal scenarios and the scenarios represented in these tests are worse than any with equivalent numbers of narrow-band interferers.
   d. These results demonstrate operation with negative S/I

ALFRED MANN FOUNDATION

January 20, 2011

Description of the MMN Graceful Shutdown process

There are two mechanisms:

1) When an implant misses communications from the master for more than 30 ms, that unit will run a program that has been downloaded to the implant units at system startup time. This program can be individual for each unit depending on clinical function and blocks all other operation until it completes. Generally, the program will be a continuation of stimulation for a short period followed by a rampdown. The test program is a simple rampdown, but nearly any pattern can be designed by the clinician and written in implant microcode.

2) When the MCU detects that an implant is (or should be) shutting down, it can send a command to the other implants in the system to activate their pre-programmed shutdown procedures. This is not a mandatory method, the master can continue to issue individual commands if so programmed.

The application program can take various actions to alert the user that the process was invoked. These may include visual or auditory warnings, specific data concerning the outage, or instructions on how to proceed. These features are determined on an application-specific basis.

MCU's Frequency Excision

As it was noted in Section 3.1, Link signal-to-noise ratio calculations, of [1], the MCU is able to operate at a much lower SNR than the ISDs. This is due to the following characteristics of the MMN network.

Firstly, tissue losses act as a natural filter by attenuating the effective power of the interference perceived by the ISDs. The ISDs do not have any frequency excision capability built-in and depends solely on the human tissue acting as an interference filter. The MCU, on the other hand, has a powerful signal processing engine with a built-in frequency excision algorithm. The specific characteristics of this algorithm were not disclosed to the Aerospace Corporation. Therefore the MCU's ability to excise frequency content was tested by simply stimulating the MCU's input and measuring signal output characteristics.

The MCU's ability to excise narrowband signals that interfere with the communications in the operating channel was tested indirectly through all the tests previously mentioned. During testing, we verified that the MCU's frequency excision engine excises the frequency content of certain bands whose energy exceeds a programmable threshold. This threshold was hard-coded into the MCU's firmware by the AMF and was not changed throughout the different experiments. As interference was injected into the operating channel of the MCU, we noted how the MCU reported the total number of frequency bins being excised. For the case of a single interferer, the number of bins excised remained relatively constant as the interference was gradually increased. At a given point, where the interference power far exceed the excision threshold, the energy present in the interferer's side lobs would also go above this threshold. At this point, the MCU would face a scenario where far too many bins needed to be excised. In order to prevent the occurrence of frame errors, the MCU would then begin a channel change procedure or alternatively shutdown. For the case where multiple interference signals co-existed in the same channel as the MCU, the effect shown in Figure 10 of [1] (reproduced below) occurs. The number of bins being reported as excised was proportional to the number of narrowband interferers.

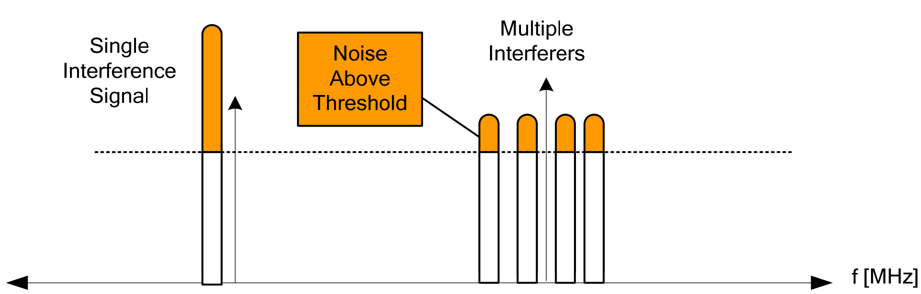


Figure 1. Noise Measurement

[1] The Aerospace Corporation "Alfred Mann Foundation (AMF) Medical Micropower Network (MMN) WIRED TEST REPORT" November 03, 2010.

Date: 1/26/2011
RE: Number of Interferers / Signal to Interference Level vs. Uplink Bit Error Rate

A test was run with 12 implant devices and a single MCU device to determine the effect of interference excision on BER performance. Due to details of the excision algorithm, some BPMs perform better than others depending on what time slot they are assigned to, though this is expected to be improved in the future. In the plots that follow, only the worst-performing time-slots (uplink) are plotted to ease readability. The blue traces, however, include all 12 uplink performances since there is no appreciable time-slot dependent loss when no interferers are present. In this test, the signal power between MCU and BPMs was varied while the total interferer power remained constant. The interference power seen at the MCU was set to be 20dB higher than the interference power seen by the implants, modeling the very worst case 20dB pad due to body attenuation. Three interference scenarios are shown in the two plots:
1) 12 tones, spaced 330kHz apart, centered in the channel 0 band, with a total power of -75dBm as seen at the MCU are injected. These tones thus appear as a total power of -95dBm to the implants. (Figure 1)
2) 6 tones, spaced 330kHz apart, centered in the channel 0 band, with a total power of -79dBm as seen at the MCU are injected. The uplink BER performance due to these tones are shown in red. (Figure 2)
3) 6 tones, spaced, 330kHz apart, centered in the channel 0 band, with a total power of -90dBm as seen at the MCU are injected. The uplink BER performance due to these tones are shown in black, although the performance appears to match that of the higher powered tones in red. (Figure 2)

Note that only a 5dB degradation for 6 interferers and 6dB degradation for 12 interferers is expected, even though the signal-to-interference ratio is well below 0dB in both plots.

Figure 1:

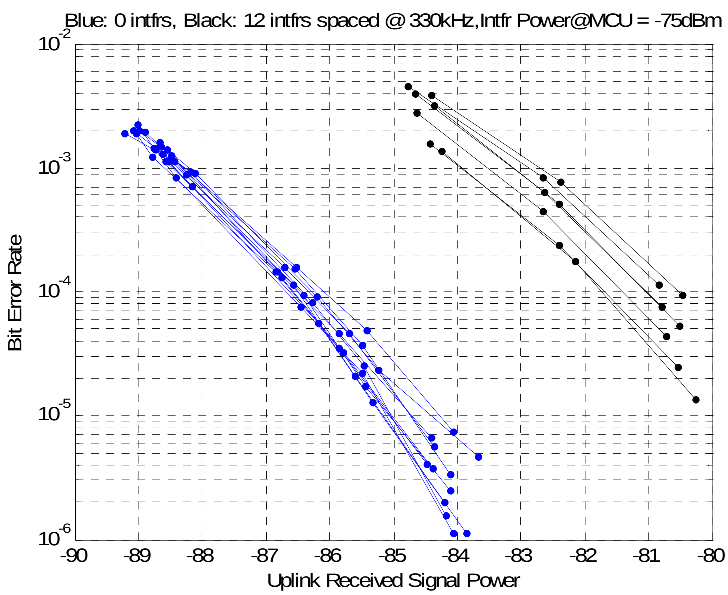
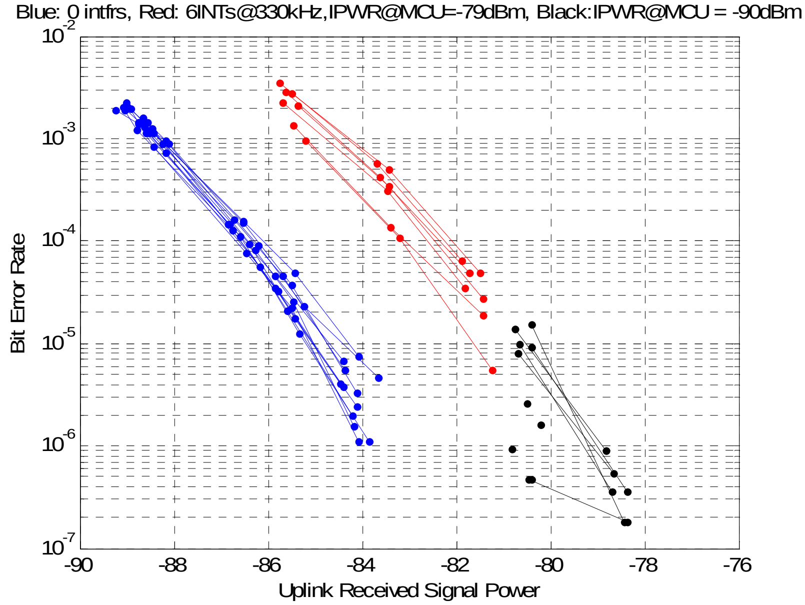


Figure 2

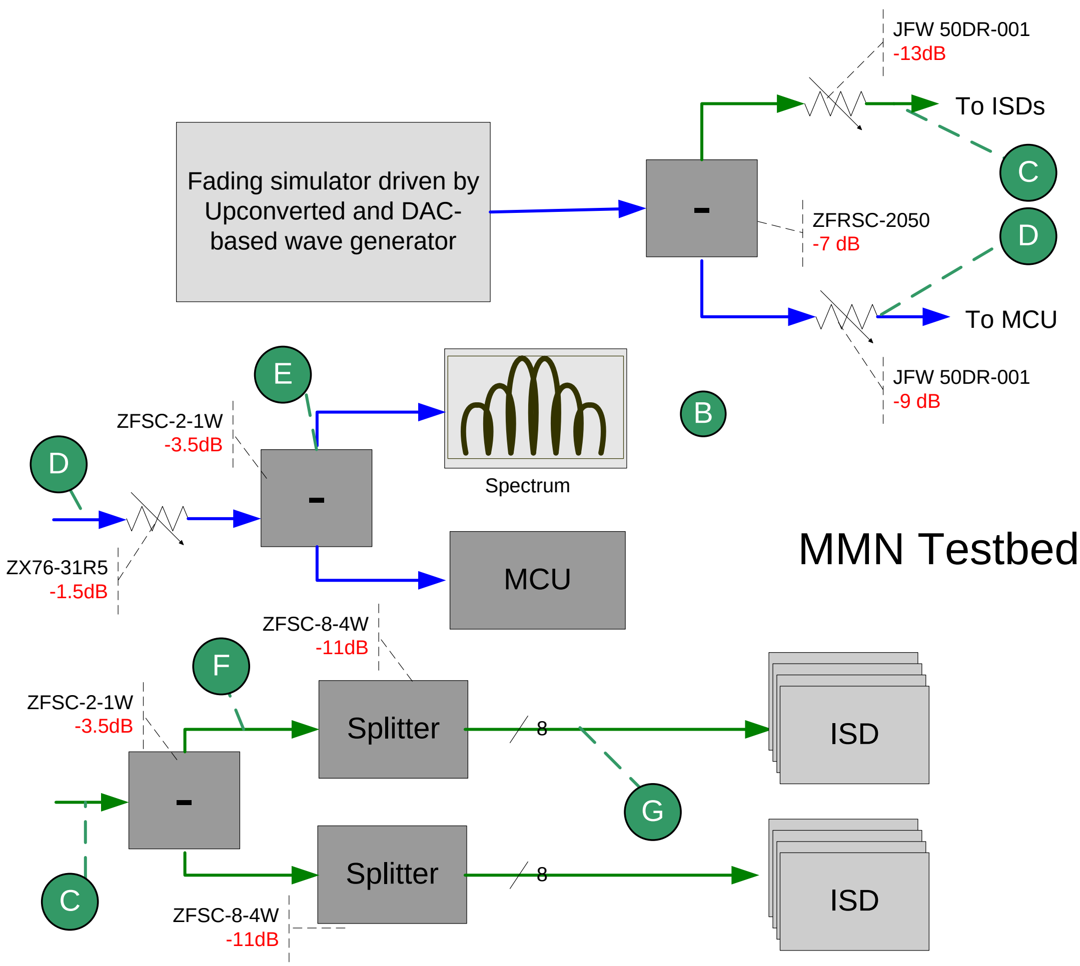


Blue: 0 intfrs, Red: 6INTs@330kHz,IPWR@MCU=-79dBm, Black:IPWR@MCU = -90dBm
Bit Error Rate
Uplink Received Signal Power
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
-90
-88
-86
-84
-82
-80
-78
-76

MMN system operation in the presence of multipath fading narrow band incumbents

January 28, 2011

The MMN wired test bench as described in the Aerospace test report was configured with an HP 11785 fading simulator and a DAC-based computer waveform generator replacing the E4438C generators in the interfering signal path



The fading simulator was loaded with a standard 6-tap GSM urban Rayleigh profile using Doppler equivalent to 38 kM/hr. The file duration was 27 seconds for each case.

Two sets of tests were run to compare the operation of the MMN interferer detection/excision mechanism under fading conditions to operation without fading.

High signal level tests were conducted to examine the effect of fading on the channel change/shutdown threshold, set at -60 dBm input power level. Since the threshold will be crossed by fading signals at nominal signal levels different from those of un-faded signals, it is expected that channel change or shutdown events will occur at some rate for such levels. For these tests shutdown events were not forced to occur, but the mechanism for channel change and shutdown under strong signal conditions is the same. Reported channel change events would become shutdown events if alternate channels were blocked. Levels from -58 dBm to -70 dBm were each run for 10 trials with 1, 5, and 10 interfering narrow-band signals all running through the fading simulator. The link path loss in the high level case was set to approximate the level used in the JSC analysis and the Aerospace testing. This level has the minimum tissue loss of 20 dB plus 20 dB fade margin and 25 dB of air path loss. These tests are severe compared to observed conditions where signals, particularly groups of fading signals, seldom reach levels around -60 dBm. In AMF test scenarios similar conditions have not appeared in signal files captured from the air.

The results tabulated below suggest that, although there is some variability in the levels at which the change/shutdown events are triggered, that level is not above -60 dBm with fading and does not occur below -64 dBm signal levels. At levels approaching -60 dBm, the changes occur with increasing frequency as the level nears -60 dBm. A few frames with errors were observed in some of the tests. This results from short-term overload of the signal processor on occasional signal peaks during fading. In no cases were these errors sufficient to disrupt the MMN link or to cause channel change events.

The second series of tests were conducted at low MMN signal levels set to emulate operation of deep implants with a 20 dB added fade margin. This level represents a path loss of 80 dB. Tests were made with interferers at -97 dBm to examine the effects of fading signals crossing the minimum noise floor, 80 dBm to set the S/I ratio to a nominal 0 dB, -70 dBm for a nominal S/I of -10 dB and -65 dBm for a nominal S/I of -15 dB. Levels above -65 dBm for five interferers represent combined peak levels over -60 dBm which the working limit for the detection/excision algorithm. The peak levels under these conditions cause some MMN link errors.

Strong Signal Performance without Fading, 27 second Tests, 2428 Frames per Run

Test#	MMN Link Level (dBm)	# of Interferers	Interferer Modulation Type	Interferer Level Start (dBm)	Interferer Level End (dBm)	Interferer Level Step (dBm)	Total Interferer Power Start (dBm)	Total Interferer Power End (dBm)	S/I Max	S/I Min	# of Frames with Uplink Errors	# of Frames with Downlink Errors	Channel Change Interferer Level
1	-63	1	FSK	-70	-57	1	-70.00	-57.00	7	-6	0	0	-60
3	-63	5	2 FM, 3FSK	-70	-57	1	-63.01	-50.01	0.01	-13	0	0	-60
5	-63	10	5 FM, 5 FSK	-70	-57	1	-60.00	-47.00	-3	-16	0	0	-60

Strong Signal Performance With Raleigh Fading 27 Second Tests, 10 Trials Each, 2428 Frames per Run

Test#	MMN Link Level (dBm)	# of Interferers	Interferer Modulation Type	Interferer Level (dBm)	Total Interferer Power (dBm)	S/I	# of Frames with Uplink Errors	# of Frames with Downlink Errors	Channel Changes in 10 Trials
1	-63	1	FSK	-58	-58	-5	0	0	10
2	-63	1	FSK	-59	-59	-4	1	0	10
3	-63	1	FSK	-60	-60	-3	0	0	10
4	-63	1	FSK	-61	-61	-2	0	0	10
5	-63	1	FSK	-62	-62	-1	0	0	4
6	-63	1	FSK	-63	-63	0	0	0	0
7	-63	1	FSK	-64	-64	1	0	0	0
8	-63	1	FSK	-65	-65	2	0	0	0
9	-63	1	FSK	-66	-66	3	0	0	0
10	-63	1	FSK	-67	-67	4	0	0	0
11	-63	1	FSK	-68	-68	5	0	0	0
12	-63	1	FSK	-69	-69	6	0	0	0
13	-63	1	FSK	-70	-70	7	0	0	0

Test#	MMN Link Level (dBm)	# of Interferers	Interferer Modulation Type	Interferer Level (dBm)	Total Interferer Power (dBm)	S/I	# of Frames with Uplink Errors	# of Frames with Downlink Errors	Channel Changes in 10 Trials
1	-63	5	2 FM, 3 FSK	-58	-51.01	-11.99	0	0	10
2	-63	5	2 FM, 3 FSK	-59	-52.01	-10.99	1	1	10
3	-63	5	2 FM, 3 FSK	-60	-53.01	-9.99	0	0	10
4	-63	5	2 FM, 3 FSK	-61	-54.01	-8.99	0	0	10
5	-63	5	2 FM, 3 FSK	-62	-55.01	-7.99	0	0	10
6	-63	5	2 FM, 3 FSK	-63	-56.01	-6.99	0	0	10
7	-63	5	2 FM, 3 FSK	-64	-57.01	-5.99	0	0	2
8	-63	5	2 FM, 3 FSK	-65	-58.01	-4.99	0	0	0
9	-63	5	2 FM, 3 FSK	-66	-59.01	-3.99	0	0	0
10	-63	5	2 FM, 3 FSK	-67	-60.01	-2.99	0	0	0
11	-63	5	2 FM, 3 FSK	-68	-61.01	-1.99	0	0	0
12	-63	5	2 FM, 3 FSK	-69	-62.01	-0.99	0	0	0
13	-63	5	2 FM, 3 FSK	-70	-63.01	0.01	0	0	0

Test#	MMN Link Level (dBm)	# of Interferers	Interferer Modulation Type	Interferer Level (dBm)	Total Interferer Power (dBm)	S/I	# of Frames with Uplink Errors	# of Frames with Downlink Errors	Channel Changes in 10 Trials
1	-63	10	5 FM, 5 FSK	-58	-48	-15	0	0	10
2	-63	10	5 FM, 5 FSK	-59	-49	-14	2	0	10
3	-63	10	5 FM, 5 FSK	-60	-50	-13	1	0	10
4	-63	10	5 FM, 5 FSK	-61	-51	-12	2	0	10
5	-63	10	5 FM, 5 FSK	-62	-52	-11	3	0	10
6	-63	10	5 FM, 5 FSK	-63	-53	-10	1	0	10
7	-63	10	5 FM, 5 FSK	-64	-54	-9	0	0	0

8	-63	10	5 FM, 5 FSK	-65	-55	-8	0	0	0
9	-63	10	5 FM, 5 FSK	-66	-56	-7	0	0	0
10	-63	10	5 FM, 5 FSK	-67	-57	-6	0	0	0
11	-63	10	5 FM, 5 FSK	-68	-58	-5	0	0	0
12	-63	10	5 FM, 5 FSK	-69	-59	-4	0	0	0
13	-63	10	5 FM, 5 FSK	-70	-60	-3	0	0	0

Low Signal Level, With Raleigh Fading. All Tests 27 seconds long, equivalent to 2428 frames. 10 Trials each.

Test#	MMN Link Level (dBm)	# of Interferers	Interferer Modulation Type	Interferer Level (dBm)	Total Interferer Power (dBm)	S/I dB	# of Frames with Uplink Errors	# of Frames with Downlink Errors
1	-80	1	FSK	-70	-70.0	-10.00	0	0
2	-80	1	FSK	-80	-80.0	0.00	1	0
3	-80	1	FSK	-97	-97.0	17.00	0	0
4	-80	5	3 FM, 2 FSK	-70	-63.0	-16.99	8	0
5	-80	5	3 FM, 2 FSK	-80	-73.0	-6.99	3	0
6	-80	5	3 FM, 2 FSK	-97	-90.0	10.01	5	0
7	-80	10	4 FM, 6 FSK	-70	-60.0	-20.00	65	0
8	-80	10	4 FM, 6 FSK	-80	-70.0	-10.00	26	0
9	-80	10	4 FM, 6 FSK	-97	-87.0	7.00	36	0

Low Signal Level Without Fading. All Tests 27 seconds long, equivalent to 2428 Frames.
1 Trial each.

Test#	MMN Link Level (dBm)	# of Interferers	Interferer Modulation Type	Interferer Level (dBm)	Total Interferer Power (dBm)	S/I DB	# of Frames with Uplink Errors	# of Frames with Downlink Errors
1	-80	1	FSK	-70	-70.0	-10.0	1	0
2	-80	1	FSK	-80	-80.0	0.0	0	0
3	-80	1	FSK	-97	-97.0	17.0	0	0
4	-80	5	3 FM, 2 FSK	-70	-63.0	-17.0	0	0
5	-80	5	3 FM, 2 FSK	-80	-73.0	-7.0	0	0
6	-80	5	3 FM, 2 FSK	-97	-90.0	10.0	0	0
7	-80	10	4 FM, 6 FSK	-70	-60.0	-20.0	29	0
8	-80	10	4 FM, 6 FSK	-80	-70.0	-10.0	5	0
9	-80	10	4 FM, 6 FSK	-97	-87.0	7.0	1	0

For all tests:

-FM signal parameters

FM deviation	5	kHz
Minimum Signal Spacing	100	kHz
Frequency Placement	Random within MMN band	
Message Signal Bandwidth	5	kHz
Message Signal Type	Gaussian Noise	

-For tests with RSSI=-63dBm, the ISD pad is 22dB.
-For tests with RSSI=-80dBm, the ISD pad is 35dB.

-FSK signal parameters

Symbol Rate	4800	symb/sec
Frequency Deviation	600	Hz
Order	4	
Message Signal Type	Uniformly Distributed	